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A STUDY OF THE DETERIORATION OF SEAKALE STOCKS, WITH NOTES ON SOME DISEASES OF THAT CROP

By W. BROWN

INTRODUCTORY.

SEAKALE (*Crambe maritima* L.) as a vegetable for forcing is grown in many private gardens but on a market scale its cultivation is to a large extent limited to the neighbourhood of London. Even there the number of growers is relatively few, but the total acreage is substantial and apart from the value of the forced "Kale" as a high-priced vegetable the crop has the merit of requiring a great deal of work during the winter months when work in the fields is at a minimum. The cultivation of seakale thus enables the grower to maintain a larger winter staff than would otherwise be possible.

A short account of the method of cultivation is given in a publication of the Ministry of Agriculture and Fisheries.* In order that the accompanying record of experimental work may be more readily understood, the essential operations, as based on the article cited and on the present writer's observations and experience, will be briefly described.

The crop is propagated by means of root cuttings prepared at the time of forcing, i.e. from November onwards. These cuttings, which are about 3-5 in. long and which should not be thinner than an ordinary lead pencil, are laid in layers out of doors, liberally dusted with lime so as to ward off Club-root disease, and covered with several inches of soil. Beyond a certain amount of additional protection against severe frost, the cuttings require no further attention.

By the middle of April, which is about the usual date for planting out, the cuttings show fine roots ("fibre") along their length and at one end, while at the other a more or less complete circle of buds arising from a callus ring appears. After a mild winter these buds may be several inches long, when it is convenient to shorten or, in fact, rub off a large proportion of them.

The rooted and budded cuttings are dibbled into the open ground, the upper end being sunk an inch or so below the soil surface. The object of this is to protect the young growth against late ground frosts, but a further advantage will be indicated latter. The standard commercial spacing is 12 in. between the plants in rows 15-18 in. apart. During the summer, in June or better in

* See Sectional Vol. No. 12, "Collected Leaflets on the Cultivation of Vegetables", 1928, pp. 80-4.

July, the plants should be disbudded, as it is found that, even with plants of best size and quality, the forced product is inferior when more than one " nose " is allowed to develop on the same plant.

In late autumn, when the foliage has either fallen off or is readily detached from the crowns, the plants may be dug up and forced. The thong-like lateral roots are trimmed off a short distance from the main axis, and used for the preparation of cuttings (variously called " thongs " or " jags ") in the way described above, while the plants themselves (called " crowns ") are placed in the forcing pit, the temperature of which should not exceed 60° F. Further details in this connection will be found in the paper referred to above.

The problems relating to seakale cultivation that demand investigation may be grouped under two headings, (1) those relating to the quality of the plants from the point of view of forcing and (2) diseases. Though a number of growers have devoted a good deal of study to this crop, their results are not generally available and, so far as the writer is aware, the information obtainable in the ordinary scientific journals is insignificant in amount. The observations to be described here relate chiefly to the question of forcing quality, but a certain amount of attention was paid to diseases as they presented themselves. Some of these are worthy of further investigation but at the moment enough is known about them to indicate their general significance to the grower of seakale.

The subject of forcing quality is bound up with the question of varietal difference, but it is very difficult to obtain any clear information on the latter point. A few named varieties are listed in catalogues (of which " Lily White " is reputed to be the best) but as things are, each grower's stock is more or less peculiar to himself. It has been grown for many years on his farm and from time to time it has been built up anew, more or less completely, from selected plants. The general experience is that, unless the grower continues to select for propagation purposes, a more or less rapid deterioration sets in and the stock, while still perfectly satisfactory as regards growth in the field, becomes of low value for forcing. A study of the nature of this deterioration formed the main subject of investigation.

EXPERIMENTAL.

The writer's attention was first directed to the problem of seakale deterioration in the early winter of 1930-1 at a farm in Middlesex. A small batch of deteriorated seakale, brought from another farm, was being forced side by side with the owner's stock. The difference in performance was very striking. Whereas the latter showed a fairly even stand and was ready for cutting, the other was nearly all dormant, i.e. as regards the large terminal bud of the crown. On the other hand numerous small side buds, which arise in the axils of foliage leaves as the plants grow in the field, had sprouted giving rise to thin " grassy "

seakale of no commercial value whatever. The deteriorated stock was scrapped, but the writer was able to obtain some 300 cuttings of it which, along with a similar number of the good sort, formed the basis of the material which has since been grown at Slough. By the second year of the work a stock of about 3,000 plants in all had been built up and it has been maintained at that level up to the present time.

Certain growers having suggested that deterioration is brought about by faulty manuring—in particular that over-manuring with nitrogen tends to deterioration whereas potash counteracts this—the work was planned in the first instance as a manurial trial and was continued as such for four years. The two stocks, which will be referred to throughout as "good"* and "bad", were grown side by side on plots which were differently manured, and their performance recorded each year. Meanwhile, propagation from individual plants of the good stock was begun. The original line of experiment was abandoned after four seasons when it was seen that manurial effects were not as important as was originally supposed, and while small lots of the good and bad stocks are still being carried on, most of the field space is now given over to some forty clone populations which have been developed. A variety of subsidiary experiments has also been carried out. The work may therefore be conveniently described under the following headings:—

(1) Manurial treatment in relation to deterioration.

(2) Behaviour of single-plant selections.

(3) Miscellaneous experiments.

(4) Diseases.

(1) MANURIAL TREATMENT IN RELATION TO DETERIORATION.

A series of fourteen plots (20′ × 10′ each), cut out of old grassland, were available and the following manurial scheme was adopted, the figures given representing rates per acre:—

2 plots, no artificials.
2 ,, ,, ,, +2 tons lime (slaked).
2 ,, 6 cwt. potassium sulphate.
2 ,, ,, ,, ,, +2 tons lime.
2 ,, 4 cwt. ammonium sulphate.
2 ,, ,, ,, ,, +2 tons lime.
1 plot, 10 cwt. superphosphate.
1 ,, ,, ,, +2 tons lime.

* As will appear later, the good stock was not all good, even in the early years of the experiment, and has now almost completely deteriorated.

The dressing of nitrogen was applied in each year, usually in two doses, in May and June, whereas the other artificials were worked into the top soil just before planting. The lime was added during the winter when the ground was being trenched.

As the soil was a light loam which had carried a poor sward of grass, all the plots received a dressing of farmyard manure at the rate of approximately thirty tons per acre which was worked into the subsoil. The same treatment was given in the 3rd but omitted in the 2nd and 4th years. Manurial treatment was thus fairly liberal and resulted in stronger growth of the plants than is commonly seen on farms.

Even in the first year of the experiment Club-root disease, which must be ascribed to contamination of the farmyard manure used, made its appearance on plants in the unlimed plots and in the second year was much worse. It was necessary therefore to lime the unlimed plots. In the winter of 1932-3 each of the latter was limed twice at the rate given above, and in the following winter the treatments were repeated, so that by the fourth year all the plots had received the same amounts of lime. By this means the Club-root trouble was reduced to small dimensions. In the light of experience it was unfortunate that the same liming treatment had not been adopted for all the plots, but in fact no difference arising from the irregularity in liming was noted. In substance, therefore, the experiment resolved itself into a comparison in quadruplicate plots (duplicate with phosphate) of the effects of excess potash, nitrogen, or phosphate on forcing quality.

Apart from the first year, in which the stock was insufficient for the purpose, fifty-four plants of the good stock and fifty-four of the bad were grown on each plot. The thongs of the two sorts from each of the various plots were kept separate and in each succeeding year were replanted on the same plot. At the end of the fourth season, therefore, there were plants of the good and bad stocks which had been grown for four years in presence of a distinct excess of potash, nitrogen or phosphorus, and others for which the manurial treatment had been more balanced. In each year the crop was forced, as a rule in 3-4 relays of batches over the period November to February, and a full record was made of average crown and kale weights and of the kale quality of the various sorts.

Before proceeding to present these results in summarized form it will be convenient at this point to outline the characteristic features of good and bad types of seakale, as seen in the forcing pit. The distinctions were more clearly seen at a later stage of the work when clones of good and bad quality were available for comparison. They are as follows:—

The good type is characterized by its stoutness, individual leaves being wide in cross section especially towards the base ; the habit is compact, so that

material of this type lends itself readily to packing without damage ; the small side buds which lie below the large terminal bud remain dormant. Conversely, the bad type may be described as spindly and sprawly, with a tendency for side buds to develop and produce "grassy" worthless seakale. The colour of the bad type is pinkish, as against the creamy or slightly yellow of the good type. For market requirements, the leaf laminae should be as small as possible, and in this respect also the stout compact type is superior to the other. Under comparable conditions, there is no material difference in the average amount of seakale produced by crowns of the two types.

The features outlined above are somewhat modified by a number of factors of which the most important are the width of the crown, the temperature of the forcing pit and the time of year at which forcing is carried out.

Width of crown is important to the extent that the total weight and the stoutness of the kale increases with crown width, but only up to a point. Very large crowns give no proportionate increase in weight of kale and very often give no increase at all. It is possible that this rule, which is in agreement with growers' experience, may be modified by suitable manurial treatment, but speaking generally it may be said that a crown width of 1-1¼ in. represents the limit beyond which any further increase in size gives no appreciable increase in yield or quality. On the other hand, crowns of small width, even when of good intrinsic quality, give kale which is lacking in stoutness and is of reduced weight. Increase in width of the crown accentuates any tendency to sprawliness and to the sprouting of lateral buds. Hence the distinctions between good and bad types tend to disappear when the crowns are small.

The temperature of the forcing pit affects both the speed of forcing and the quality of the product. With higher temperatures the kale is less stout and there is some evidence that the amount of lamina development is increased.

The effect of time of year is, however, the most notable. In early forcings, beginning say at the end of October, the difference between good and bad types is pronounced. At this period the terminal buds of the latter are liable to remain dormant while the small lateral buds develop freely and produce "grass". Crowns of good type force at this stage more quickly and evenly, but even these are not entirely satisfactory. Thus, while in later forcings a crown of good type would show 5-8 leaf stalks extended, a similar crown when forced early in November might have only one or two stalks of full length, with perhaps a few short ones in the centre of the bud. As a result of this the weight of kale per crown is low in early forcings, even when extra time is allowed, and the habit moreover is inferior, as the long outer stalks tend to diverge and often to twist.

In December forcings both types start fairly evenly, and later still, e.g. at the end of January, the bad type forces somewhat more quickly than the good. The sprouting of side buds which is characteristic of the bad type is still

pronounced in December forcings, but towards the end of the season is much reduced. With both types the flowering axis tends to "push" as the season progresses, and this tendency is greater in the good than in the bad type.

Representative samples of bad and good types are illustrated in Figs. 1 and 2.

The outstanding result of the manurial experiment was that no treatment made the bad stock good and that the good stock remained more or less good under all treatments. A few good plants were present in the bad stock up to the second year but after that they disappeared entirely. The good stock has also deteriorated as is shown in Table I, which gives the percentage of crowns producing stout seakale in the grouped series of manurial plots. Each figure in the Table is the average obtained from three forcings, the component figures showing good agreement. Comparable data are lacking for the first year of the experiment (1931), as facilities for forcing were not then available at Slough.

TABLE I.

Percentage of crowns giving stout seakale under different conditions of manuring.

	1932.	1933.	1934.
Control Plots	48	37	20
Potash Plots	54	54	41
Nitrogen Plots	42	43	34
Phosphate Plots	40	38	24

As has been stated, the basis on which the plants were graded was stoutness of leaf-stalk. It is admitted that the standard adopted might vary somewhat in different years. Furthermore, the average crown weight decreased to some extent in each succeeding year (3·05 oz. in 1932, 2·8 in 1933, 2·5 in 1934) and this in itself would rather reduce the percentage of plants which gave stout seakale. There is, however, no doubt that deterioration has taken place. The figures in the Table are underestimates, since all small crowns, even those of good type, would be graded as producing inferior seakale. The percentage of plants of good forcing quality was undoubtedly higher, and probably much higher, than 50% in 1932, whereas in the past year (1936), it had definitely sunk to 17%, as determined by foliage examination of the growing crop. It was unfortunate that this mode of distinguishing between good and bad plants, which was not discovered until 1935, i.e. after the manurial experiment was finished, was not known earlier, since by that means the progress of deterioration could have been more accurately followed.

The criticisms in the foregoing paragraph do not apply to gradings made on any one date, and therefore there is a definite suggestion that manurial

treatment affects the rate at which deterioration proceeds—viz. that it is greatest in the control plants and in those treated with phosphates, least in the potash and intermediate in the nitrogen plots. To the extent indicated therefore, the system of manuring influences the progress of deterioration, but it is doubtful if much importance is to be attached to this result. In the light of what will be pointed out later regarding the rooting habits of good and bad forcing types of plants, it is probable that the general level of manuring and the depth to which the soil is worked are factors which would have to be taken into account in this connection.

Throughout the run of the manurial experiment a complete record was kept of the weight of crowns and of forced seakale from both stocks on all the plots. No substantial difference arising from the different inorganic manures added was established. Perhaps the liberal treatment with farmyard manure was sufficient to mask any effects of the artificials in this respect.

The growth of the two stocks on the variously manured plots was followed in detail in season 1933 by recording on two dates the sizes of the above-ground portions of the plants. Four grades of size—large, medium large, medium and small—were decided upon and the whole crop of some 1,500 plants in the manurial plots was thus graded. In thirteen of the plots the bad stock was clearly ahead of the good in general vigour of growth ; in one plot only was there no noticeable difference. The results of this survey, summarized for the whole fourteen plots, are set out in Table II, which gives the percentage of plants which fall into each size-class.

TABLE II.

Percentage of plants, in good and bad stocks, arranged according to grade at two periods.

Date.	Stock.	Large.	Medium large.	Medium.	Small.
June 19th	Good.	28·3	37·3	24·4	10·0
	Bad.	46·8	35·8	13·2	4·2
July 12th	Good.	26·4	39·4	27·4	6·8
	Bad.	51·4	32·8	12·9	2·8

The figures in the Table show clearly that the bad stock was the more vigorous in growth on both dates of inspection.

In a smaller experiment, with 250 plants of each stock, the growth vigour of the plants on July 12th was correlated with the diameter of the crowns when lifted at the end of October. In Table III the first column of figures gives the number of plants (out of 250) which fell into the various size-classes in July, and the remaining columns give the number of crowns of various sizes at lifting time.

TABLE III.

Correlation between vigour of growth in summer and crown diameter at time of forcing.

Stock.	Size-Class.	No.	Mis-sing.	¾ in. or less.	⅞ in.	1 in.	1⅛ in.	1¼ in.	1⅜ in.	1½ in. or more.
Good	Large.	51	0	0	9	21	12	6	2	1
	Medium large.	96	0	11	36	27	20	1	1	0
	Medium.	84	4	49	24	6	1	0	0	0
	Small	19	6	12	0	1	0	0	0	0
Bad.	Large.	135	0	4	13	32	42	21	14	9
	Medium large.	80	0	13	21	23	12	7	3	1
	Medium	26	2	13	5	3	1	2	0	0
	Small.	9	3	3	0	0	1	0	1	1

This Table again substantiates that the bad stock is characterized by greater growth vigour in the field and that in both stocks the groups which are graded as vigorous in July tend to give the largest crowns in October. These results were borne out by the greater average crown-weight of the bad stocks at the time of lifting, viz.:—

Bad stock, 3·32 oz.; good stock, 2·86 oz.

In carrying on the stocks from year to year a record was kept of the number of root cuttings ("thongs") made. A definite standard of size was adopted, viz. a length of 4 inches and a diameter of at least ¼ inch (comparable to an ordinary lead pencil). With the good stock it was necessary in the first year to break this rule, i.e. in certain cases to cut thinner thongs, in order that a sufficient number of cuttings should be obtained. Even so, the figures of Table IV illustrate the invariable experience that the root system of the bad stock was more satisfactory for the preparation of standard cuttings. The figures in the Table give the average number of cuttings per plant.

TABLE IV

Relative number of thongs from good and bad stocks over a period of four seasons.

Year.	Good Stock.	Bad Stock.
1931	2·8	4·2
1932	4·6	4·8
1933	2·3	3·8
1934	2·5	4·0

Thus, in any mixture of good and bad types in a stock there is the likelihood that a higher percentage of thongs will be cut from the bad type than

corresponds with the original admixture, so that in successive years the percentage of the bad type will tend to increase. This fact alone, in the writer's opinion, is the chief if not the only reason for the observed deterioration of a stock.

The difference in rooting habit indicated above is shown in the early behaviour of root cuttings. Thongs of the bad forcing type begin to "fibre" more quickly than those of good type under the same conditions.

A third point of difference between the two stocks, as seen in the field, shows up clearly in the autumn, e.g. in October, and especially after there has been a slight ground frost. This difference is still more clearly marked with the clone selections. At this date the leaves of the good type have practically all collapsed and fallen to the ground whereas in the other they are still vigorous and attached to the plant. In other words the good type of plant ripens first. This difference throws a light on the experience in the forcing pit where it is found that early forcings of the bad stock show a pronounced tendency to dormancy of the main buds.

(2) BEHAVIOUR OF SINGLE-PLANT SELECTIONS.

In the spring of 1932, rooted and callused thongs were taken at random from the good stock and planted separately in good garden soil. Though all these were not carried on, the first year's records showed that 26 out of 34 were of good forcing type. During the winter of 1933-4 a further batch of selections was begun, but in a somewhat different manner. A number of plants of good size were marked out in the field. When these were lifted only the ones which had good root systems, i.e. which would give about six thongs for propagation, were used. The thongs were put to callus in separate beds and the crowns were forced in the usual way. Of this batch it is interesting to note that only 8 out of 29 proved to be of good forcing type. At that time the proportion of good plants in the stock was undoubtedly much higher. The method of selection, viz. the choice of good sized plants with good root systems, was clearly responsible for the large proportion of bad plants obtained. This result is a further confirmation of what has been said above regarding the rooting habits of the two types of plants.

Many of the bad types were discarded at once, and some after a few years, but altogether 38 selections are now being carried on. Of these 24 are are of good and 14 of bad type. Of some the records of performance are available over five, of others over four years.

The result up to the moment is that no definite change has been noted in the forcing character of any of the selections. From time to time a suspicion of deterioration in some of the good types has been recorded, but so far it has

not been confirmed in the year following. There is from year to year a certain amount of fluctuation, but this can be set down to variations in the dates of forcing. The good types are not all the same, though many are indistinguishable and some are definitely inferior to others. A short description of a few of the selections of good type will serve as illustration.

Selection A : Over five seasons this has invariably given stout seakale of compact habit ; lateral buds almost always remain dormant in the forcing pit.

Selection B : A type characterized by weak, bluish foliage which dies down very early ; the root system is relatively good ; crowns force very quickly at the beginning of the season ; the seakale is not stout enough but the habit is compact and side buds remain dormant.

Selection N : A type which produces stout, compact seakale but shows a distinct tendency for a number of side buds to develop.

Selection U : Later in maturing than B and forces more slowly early in the season ; root system weak and finely divided ; excels B in stoutness of seakale produced.

Only in one case—Selection E—which is a good though weakly growing type, has anything untoward occurred. In 1936 six plants of definitely bad type suddenly appeared in a stock of about 150 plants. As this is the only example of deterioration which has been met with so far, the most plausible explanation at the moment is that accidental admixture is responsible.

With a few of the original selections, considerable difficulty has been encountered in maintaining the stock, and in fact some have had to be abandoned. The plants were small with poor root systems, and satisfactory thongs could hardly be obtained. Possibly fungoid disease was the cause of this, but the question was not taken up.

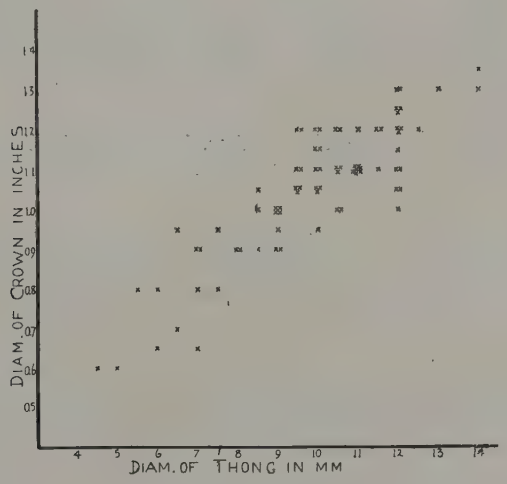
The results so far obtained with these clones have not confirmed the assertions of growers that good plants tend to revert. The occasional throwing of sports of bad type by good plants is not impossible, but with one doubtful exception this has not happened yet in the history of these clones. While the results already obtained explain why, in a mixture of good and bad types, the method of propagation tends to increase the proportion of the latter, they have not as yet indicated the manner in which the bad type arises in the first instance.

During the summer of 1935, by which time plots of the clones were available for comparison, a distinct difference was noted between the leaves of good and bad types. Later it was learned that the fact was known to some growers. The difference lies in the serrations of the leaf margins. These serrations are numerous and sharply pointed in leaves of bad type (termed " hollyleaved " by growers) ; in those of good type they are larger and blunter or even lobe-

like. The difference is not clearly seen in young plants ; it is best seen when the plants are in full growth, and then it is equally noticeable in the full-grown leaves and in the young crumpled leaves towards the centre of the plant. Some of the clones, viz. the weakly growing type with bluish leaves, show the sparsely notched flat-lobed appearance most distinctly.

(3) MISCELLANEOUS EXPERIMENTS AND OBSERVATIONS.

(a) *Relation of thong-size to crown-size.* While the length of the thong is, within wide limits, of no importance, the width has a direct effect upon the diameter of the resulting crown and therefore, within limits, on the stoutness of the kale produced.



Text-fig. 1.

Illustrating relation between diameter of thong and diameter of the resultant crown.

Text-fig. 1 gives the result of an experiment in which eighty thongs of known diameter were followed through a season's growth and the diameters of the resultant crowns determined. While there is obviously a good deal of irregularity, the general tendency is clear—that the thong of a greater diameter is the more likely one to produce a crown of large diameter. Some idea of the minimum thong necessary to produce the commercially ideal crown can be obtained from such a diagram, but variations in soil and season would also have to be taken into consideration.

(b) *Natural disbudding of plants.* The growers' practice is to disbud the plants at least once during the growing season so as to avoid the occurrence

of multiple-nosed crowns. In a number of experiments with plants of the good and bad stocks, disbudding was purposely omitted and records were obtained illustrating the natural disappearance of buds as the season progressed. At the time of planting in the field the rooted cutting may have a more or less complete ring of buds at its upper end. The following records of two plants will serve to show how this large number of buds is progressively reduced by a natural process.

(1) Cutting with a complete ring of buds, planted on April 16th ; on June 10th, the plant showed 3 large and 3 small buds ; on July 2nd, 3 large and 1 small bud ; the crown when lifted in winter had 1 main bud and 2 secondaries (corresponding to the three large buds of July 2nd).

(2) Cutting with a complete ring of buds, planted on April 16th ; on June 10th, the plant showed 1 large, 2 medium and numerous small buds ; on July 2nd, 1 large and 1 small bud ; on lifting the crown had 1 bud only.

Observations of this nature showed that, in general, the final condition of the plants as regards buds could be foretold accurately from an inspection in July.

In records obtained over three years, plants of the good stock have shown a distinctly greater tendency than those of bad stock to disbud themselves. The data obtained, in terms of percentage, are given in Table V.

TABLE V.

Relative amounts of natural disbudding of good and bad stocks.

	Stock.	1-nosed.	2-nosed.	3- or more nosed.
1932 ..	Good.	38	52	10
	Bad.	30	42	28
1933 ..	Good.	48	38	14
	Bad.	35	40	25
1934 ..	Good.	56	22	22
	Bad.	20	44	36

The results in Table V and the comparative forcing behaviour of good and bad types can be summarized in the statement that the former show greater dominance of the apical bud. In the field, with no artificial disbudding, the leading bud in plants of good type has a greater capacity to suppress smaller buds, and this feature is more pronounced in the forcing pit. Whereas the apical bud of a plant of good type is dominant to side buds at any period of the forcing season, a progression with plants of bad type can be noted. Early

in the season, e.g. in November, side buds are liable to be dominant to and to suppress the main bud ; later, as in December, both main bud and side buds force freely ; but towards the end of the season the main bud tends to become more dominant.

(c) *Polarity of roots.* As is well known, the formation of buds at the morphologically upper end and of new roots at the other end of a root cutting is independent of the orientation of the latter in the ground. On the other hand, the development of buds at the wrong end of roots has frequently been noted on the stubs of roots which are left on the crowns while the latter are being forced. It is very common to find buds arising among the roots under these conditions, but the majority of these are lateral to the roots, generally at wounds. Nevertheless numerous instances have been noted in which their origin is strictly terminal, viz. on the cut surface. It is suggested that this reversal of polarity may be due to temperature or moisture gradients within the soil of the forcing pit. Crowns with such abnormally placed buds have been planted, but these buds have invariably died off and the crown has formed a callus and buds in the normal position.

(4) DISEASES.

Club-root. The occurrence of this has already been mentioned. Heavy liming prevents it from becoming serious, though in 1936 it was unpleasantly prominent in plots which had been dunged and which had been limed at the rate of two tons per acre in the preceding year. Affected roots are swollen and soon become black. No obvious effect on plant growth has been observed and when the galls are confined to the side roots the only damage is the loss of the latter for the preparation of cuttings. Very often, however, galling of the base of the crown occurs and then the loss is serious, as such a crown rots from below upwards when put into the forcing pit. Forcing of the bud is thereby retarded and often completely prevented.

Copper-web Disease due to *Rhizoctonia Crocorum* has been met with occasionally, more particularly on the distal parts of roots. Very rarely has its presence interfered with forcing of the crown.

Disease due to *Rhizoctonia Solani.* In the forcing pit the leaf stalks, usually at the base but sometimes higher up, are blackened and rotted. Exceptionally the whole bud is attacked so that the seakale topples over. From such affected plants *Rhizoctonia Solani* has regularly been isolated, and inoculations of this fungus into the developing kale have proved successful. This trouble is probably best controlled by seeing to it that the tops of the crowns are raised above the level of the soil of the forcing pit.

A more interesting occurrence of this fungus is seen on the plants in the field. It has been noted above that a considerable amount of natural disbudding takes place as the plants grow. Some buds forge ahead of the others and the latter in due course are suppressed. As these weak buds are in process of dying they show a blackened cortex, and from this *Rhizoctonia Solani* is readily isolated. From time to time the fungus attacks the leading buds also and so the whole plant is killed. Hence the bare patches which have occasionally occurred. Usually, however, the fungus is able to destroy the weakened side buds only, so that up to a point its activity is beneficial to the cultivation of the crop.

A number of subsidiary experiments, in which cuttings were planted so that their tops were just above ground level, tend to confirm the view that the fungus plays a significant part in bringing about natural disbudding. Such high planting would serve to remove the developing buds from the influence of soil fungi. Table VI gives the results of one such experiment in which a comparison was made of the final condition of crowns derived from high-planted as against normally planted thongs. Two other experiments in different years gave the same result.

TABLE VI.

Effect of method of planting on natural disbudding.

Stock.	Method of Planting.	Condition of Crown.			
		1-nosed.	2-nosed.	3-nosed.	4- or more nosed.
Good.	High.	3	5	9	5
	Normal.	13	5	3	2
Bad.	High.	1	8	4	10
	Normal.	5	11	6	3

BLACK STREAKS IN ROOTS. Not infrequently one sees black dots in cross sections of roots. These correspond to strands of blackened tissue, usually but not always fairly central, which run for some distance along the root. It was early seen that forcing quality is not closely related to the presence or absence of black streaks in the roots inasmuch as they were as frequent in the good stock as in the bad. The writer's practice has been to discard for purposes of cuttings any roots in which the internal blackening is pronounced. In one experiment a number of internally blackened thongs were found to form buds and roots in a perfectly satisfactory manner. Twenty-seven such thongs were planted out and though the growth was uneven, all except one gave crowns of normal average size in the autumn. Their forcing behaviour was however very bad, but this result was due, in part at least, to Club-root. Thongs cut

from these plants showed no more internal blackening than usual. Further experiments as to the cause of the blackening and as to its significance in the production of seakale are in progress.

Soft-rotting of the crown, with the production of a grey coloured semi-liquid mass, has occasionally been observed.

Bad Fibering of the crowns in the forcing pit appears to be due, apart from some of the fungi mentioned above, to too high a temperature in the forcing pit. This is most often met with in crowns which are situated immediately above the water pipes. The cut ends of the roots become black and no new fibres are produced. With high moisture content of the soil the ends of the roots become rotted. The effect on the kale is a slowing down of forcing.

Virus Disease. The sporadic occurrence of leaf mottling has been observed and is suggestive of virus disease though it has not been proved to be such. The appearance usually takes the form of a vein clearing, the leaf tissue lying along the veins being of a lighter green than the rest of the leaf. This effect is much more distinct in some plants than in others. There is an indication that the clones which are the weakest growers are the ones which are most affected.

The possibility that deterioration in forcing quality might be due to virus disease was considered and for this purpose a number of grafts were made. Altogether twenty-six such composite thongs were made, the upper portion being of good type and the lower of bad. All these graftings were successful and the plants grew in the usual manner. When these crowns were forced they all gave kale of good type. Thus, in spite of organic union, no bad feature had been communicated to the apical bud. The experiment was continued further by cutting off the good upper part of the crown, in those cases where the junction was still visible, rooting it and growing on for another season. Again the kale produced was of good quality and the thongs produced gave plants of good type. There was clearly no evidence of a transmitted virus dsease.

DISCUSSION.

The foregoing results indicate clearly that the main cause of the deterioration of seakale stocks is the presence of plants of bad type, the proportion of which tends to increase on account of the method of propagation adopted. Plants of bad type are strong growers, and what is probably more significant, begin to grow more quickly and to form a larger root system in the spring. As the commercial spacing in the field is rather close, the roots are under highly competitive conditions so that the intrinsic difference in root-growth is probably accentuated where the two types are grown intermingled. This would tend to

the more rapid submergence of the good type in the stock. That conditions are highly competitive is indicated by the fact that plants at the edges of the plots have as a rule been found to possess very long roots.

While manurial practices, depth of cultivation, spacing, and seasonal effects are factors which would appear likely to influence the rate at which deterioration proceeded, the major fact is that deterioration will continue so long as plants of bad type are present. Hence the desirability of their removal. In a stock which contains a small proportion of such plants, rogueing could be carried out in the field on the basis of leaf characters, at a time when the root system is small. Rogueing at a later date would be less effective, inasmuch as broken roots of a size suitable for thongs would be left in the ground and might be used for cuttings. Where there is a high percentage of bad plants in the stock, the only feasible procedure is to build up the stock anew from plants of good forcing quality. Merely to propagate from some good plants each year and in due course to add the new stock to the old so as to give a general leavening effect would seem to be a waste of effort. The stocks, old and new, should be strictly segregated, until such time as the old one can be discarded entirely.

A certain amount of deterioration in relation to cropping capacity may also be traceable to fungoid agency and to virus disease. Further work is necessary to determine these points.

The writer's experience of the behaviour of single-plant selections runs over five years only and is admittedly limited. The possibility that plants of good sort may throw sports of bad type from time to time cannot be overlooked ; indeed, occasional plants have been observed which show peculiar features, e.g. red or albino leaves or portions of leaves, and these have presumably arisen by sporting. Nevertheless the fact remains that no clear deterioration has arisen in the twenty-four single-plant selections of good type which are being maintained, and it will be noticed that the system of cultivation was such as to lead to a rather rapid deterioration of the originally good—and mixed—commercial stock. Further experience of the behaviour of these selections will show how far a liability to sporting will interfere with the maintenance of a pure stock of good type.

The problem of the effect of manuring on the forcing behaviour of a good stock has not been tackled in this work. The influence of the standard manurial constituents—K, N and P—on the maturing of the crop and on the finer qualities of the forced product would be worthy of careful study, but it did not seem advisable to consider such points until a pure stock of plants of good type was forthcoming.

The writer wishes to express his great indebtedness to Mr. H. B. Montgomery for his assistance in various phases of this research ; more particularly for the

FIG. 1.
Crowns of forced seakale of bad type.

FIG. 2.
Crowns of forced seakale of good type.

large amount of detailed recording which he carried out in season 1933, and for much help in tabulating the notes relating to several seasons' work.

SUMMARY.

1. In a study of the deterioration of a good stock of seakale, manurial treatment was found to be a factor of secondary importance. The cause of deterioration is the presence in the good stock of a number of plants of bad forcing type, and the proportion of these tends to increase as a result of the method of propagation adopted.

2. The characteristic differences between plants of good and bad forcing type are outlined. These differences relate to growth vigour in the field, leaf shape, date of maturity, development of root system and forcing behaviour at different periods of the season. Plants of good type show, both in the field and in the forcing pit, a greater tendency for one bud to become dominant over all others.

3. The history of a number of clones, some of good and some of bad type, is recorded. None of the clones of good type has, up to the present time (i.e. after 4-5 seasons) shown any significant deterioration.

4. Diseases of seakale, as they have been encountered in the experiments, are recorded and briefly described.

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INCOMPATIBILITY AND STERILITY IN THE SWEET CHERRY, *PRUNUS AVIUM* L.

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INTRODUCTION.

The work on incompatibility and sterility in cherries and other fruits, in progress at the John Innes Horticultural Institution, has been reported upon from time to time (Crane 1923-7, Crane and Lawrence 1929-31). The experiments have been continued each succeeding year on trees grown in pots, under the methods of control described in earlier papers. The last report, published six years ago, dealt with the genetical aspects of the investigations and in particular with the hereditary basis of incompatibility. In the present report the results obtained during the last six years are described, and both the practical and the genetical aspects of the experiments are considered. The results of the work with seedlings are summarized, but those obtained from pollinations with established varieties of cherries are given in detail.

The material used in the experiments here reported upon has consisted mainly of varieties and seedlings of *Prunus avium*, the Sweet Cherry. But *Prunus Cerasus*, the Sour Cherry, and the hybrids between these species, collectively known as the Duke Cherries, have been used in the pollinations, and to a small extent *Prunus decumana* and *P. cantabrigiensis*.

In the genus Prunus the basic chromosome number is 8. At the time the last report was published a number of the varieties of Sweet Cherry we had used were thought to be aneuploids possessing one or more chromosomes beyond the diploid number (Darlington 1928-30). Since then Darlington (1934) has re-examined a number of such varieties and found them all to have 16 chromosomes ; and there seems little doubt that all varieties of the Sweet Cherry are diploids ($2x=16$). This is in agreement with the cytological studies of Ewert (1922), Kobel (1927) and Prywer (1936). Of the other species used in the experiments, *Prunus decumana* is diploid, $2x=16$ (Darlington 1928) ; the Sour Cherries, *Prunus Cerasus*, and the Duke cherries, *P. Cerasus* × *P. avium*, are tetraploid, $4x=32$ (Kobel 1927, Darlington 1928). *Prunus cantabrigiensis* is also tetraploid, $4x=32$ (Fabergé, unpublished). This species was described by Stapf (1926). It is a native of China and was formerly confused with *Prunus pseudocerasus*. In this country it has been distributed under the varietal name of " Chinese Early ".

The varieties used in the experiments and the results obtained from numerous self- and cross-pollinations are given in the appended Table IX. In

this table the varieties are arranged in alphabetical order. Cross-incompatible pollinations, when they occur, are detailed at the beginning of the columns and are printed in italics. Then follow the results obtained from inter-varietal compatible pollinations, and finally, at the ends of the columns, the results are given of pollinations between the diploid Sweet Cherries and the tetraploid Sour and Duke Cherries.* Hitherto but few of the results have been published and practically none since 1925. Prior to 1925 the pollinations were made on a comparatively small scale ; since then a large number have been repeated, and the total results are given in Table IX. The numbers recorded in the Tables are of "fruits matured" not fruits set.

INCOMPATIBILITY.

The results of the pollinations between the varieties of the Sweet Cherry detailed in Table IX show that all the varieties tested are self-incompatible and that cross-incompatibility is common. As a rarity, fruits have formed following both self- and cross-incompatible pollinations. The proportion of such fruits, 0·1%, is, however, very small and their occurrence is discussed later. Out of a total of 66 varieties investigated 45 have been found to belong to 11 incompatible groups. A few of these varieties have only recently been assigned to their respective groups, and in some cases the pollinations require repetition ; but from general experience we have little doubt of the validity of the available results. The remaining 21 varieties are, so far, independent of any group, but some of them have not been extensively used, and further work is necessary before it can be concluded that they do not belong to any of the 11 groups so far established, or to additional groups.†

Self- and cross-incompatibility are often referred to as self- and cross-sterility. It may be pointed out, however, that when dealing with the phenomenon of incompatibility we are not concerned with sterility in the strict sense of the word, as in the former the pollen and the ovules, or at least a high proportion of them, are functional. The failure to obtain fruit from self- and cross-incompatible pollinations is due to the arrest of pollen-tube growth in the stylar tissue. The pollen tubes fail to reach the ovary and fertilization cannot take place ; and, since the formation and development of the fruit is dependent upon fertilization, the young unfertilized fruits cease to grow, and fall from the trees at an early stage (see Fig. 1). In the compatible pollinations,

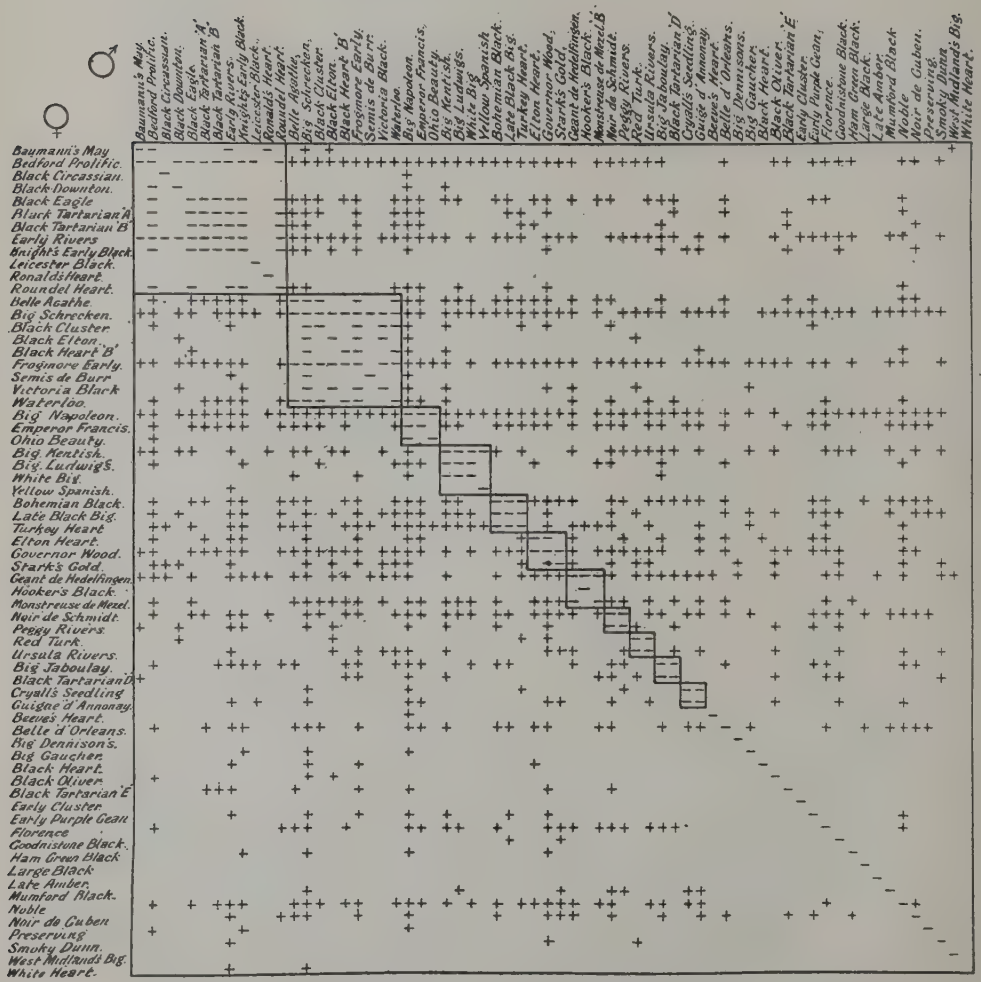
* In Table IX. the tetraploid varieties are indicated by an asterisk.

† While this paper has been in the press the results of another season's work (1937) have become available and indicate that Late Amber and West Midlands Big. belong to Group IV. The results are :—

Late Amber × Big. Kentish, 24 flowers, 0 fruit ;
Big. Kentish × Late Amber, 17 flowers, 0 fruit ;
West Midlands Big. × Big. Kentish, 59 flowers, 0 fruit.

TABLE I.

Incompatibility in varieties of the Sweet Cherry.



(+ = compatible ; − = incompatible pollinations.)

however, although the same pollen and ovules (in different combinations) may take part, the pollen tubes travel the full length of the style, the male and female nuclei fuse and the fruit develops.

The co-incompatible varieties, the groups to which they belong and the effective and non-effective pollinations are shown in Table I.

The gross totals of (a) self-pollinations, (b) cross-incompatible pollinations and (c) cross-compatible pollinatons made between varieties of the Sweet Cherry and the results obtained are summarized in Table II. The results obtained from pollinating the Sweet Cherry with the Sour, Duke and other species are also given in this Table.

Table II.

Sweet Cherries (*P. avium*).	No. of flowers pollinated.	No. of fruits matured.	Percentage matured.
Self-pollinations	49,160	30	0·06
Cross-incompatible pollinations	30,847	33	0·11
Cross-compatible pollinations	130,356	29,439	22·58
Pollinated by Sour varieties (*P. Cerasus*) ..	4,205	841	20·0
Pollinated by Duke varieties (*P. Cerasus* × *P. avium*)	4,947	747	15·1
Pollinated by *P. cantabrigiensis*	101	3	2·9
Pollinated by *P. decumana*	387	101	26·1

The experiments of many other investigators, amongst whom may be mentioned Gardner (1913), Schuster (1922-5), Florin (1923), Wellington (1926), Tufts, Henrickson and Philp (1926), Sachoff (1931), Schandert (1932), Einset (1932), Kobel and Steinegger (1933), Wenholz (1936) and Johansson and Calmar (1936), have shown that in the Sweet Cherry self-incompatibility is the rule and that it is exceptional to obtain a fruit from self-pollination. Several of the above investigators have also found examples of cross-incompatibility, and in their recent paper Johansson and Calmar (1936) have shown that the varieties Coe's Transparente and Lucie are co-incompatible and belong to the same group as Early Rivers, i.e. our Group I.

References to the occurrence of self-compatibility in the Sweet Cherry are rare, and lack conviction. Pashkewitch (1930) reports that at one Russian station the varieties Yellow Donissen, Big. Napoleon and Black Dayber are self-fertile under natural self-pollination, whatever that may be, and set 44, 57 and 64% of fruit respectively (see Russian text, pp. 38-9). In our experiments Big. Napoleon set only 2 fruits out of a total of 1,429 flowers self-pollinated. This variety has also been extensively investigated in other countries and has been found to be almost or entirely self-incompatible. The results reported by Pashkewitch are therefore exceptional, but the statement he makes that the results were obtained under natural conditions suggests that the

pollinations were not controlled, and if such was the case the results are of no value. In other stations in Russia the three varieties mentioned above, and many others, were found to be self-incompatible. The short summary in English appended to the report definitely states that the varieties are self-fertile, and this has been quoted in English publications. This summary, however, appears to be misleading, and we are indebted to our colleague Dr. A. C. Fabergé for translating the Russian text of Pashkewitch's report.

In a recent statement Salisbury (1935) implies that the variety Hertfordshire Black is self-compatible, but no details are given. Apparently Hertfordshire Black is one of the varieties in cultivation, allied to, or which come under the name of, Corone or Caroon. This appears to be the name of a group, consisting of a number of similar individuals, and not the name of a single variety. Referring to Corone, Bunyard (1925) for example, states, "This comes fairly true from seed and there are therefore many varieties in cultivation which exhibit slight differences." It therefore seems possible that in practice very similar but distinct individuals may be cultivated under the name of Hertfordshire Black, and that they may effectively pollinate each other. We have endeavoured to obtain this variety, but so far without success, and we should be grateful for any information as to where either young trees, or shoots for budding and grafting, of Hertfordshire Black can be obtained. A self-compatible variety would be of outstanding value in genetical research, and since theoretical conclusions indicate that a self-compatible variety is likely to be universally effective on self-incompatibles it might be of considerable practical value.

STERILITY.

It is shown in Table II that the average set of fruit obtained from the cross-pollinations made in these experiments is 22%. This approximates to a good yield, but as the results detailed in Table IX show, among these compatible crosses very considerable variation occurs. Environmental factors such as the age of the tree, the kind of crop it carried in the previous year, and whether flowers were borne abundantly or otherwise, are frequent causes of such differences. Experience has shown that the results of individual pollinations cannot always be relied upon, as in many cases an initial poor set has on repetition given a high yield. In particular, very young trees have often given a comparatively poor set of fruit, whereas when older, the same cross-pollinations have resulted in heavy crops of fruit. The comparatively low yields so far obtained from the varieties Baumann's May and Beeve's Heart following compatible pollinations (see Table IX) are probably examples of the above. Both are young trees recently introduced into the experiments. When, however, due allowances have been made for the influences of the above-mentioned and

other environmental factors, it is clear that although they play the larger part, they are not the only cause of the variation. In certain cases it appears that degrees of generational sterility affect the proportion of fruits which set and reach maturity. This naturally will be more evident on the female than on the male side ; for, whereas a moderate or even a fairly high proportion of bad pollen might not detract from the effectiveness of a variety as a pollinator, a similar proportion of sterility among the ovules might result in a lower yield. For example, as shown in Table IX, Black Tartarian "A", when used as female, has given a low yield in numerous crosses, and it is significant that this variety has a comparatively low proportion of good pollen (see Table VI).

A comparison of Figs. 2 and 3 shows that from a number of compatible pollinations, Black Tartarian "A" (Fig. 2) gave only an average set of 10·3%, whilst Big. Napoleon (Fig. 3) gave 55·9%. Reference to Table IX also shows wide differences in the yield of these varieties. The highest proportion of fruit obtained from Black Tartarian "A" is 21%, whereas from Big. Napoleon over 60% has frequently been obtained. There seems little doubt that the consistent low yield obtained from Black Tartarian "A" is due to a fairly high proportion of sterility operating on its female side. Although not so wide, similar differences are evident among other varieties.

It is possible in certain cross-pollinations that, in addition to a degree of generational sterility, a proportion of the pollen may also be incompatible, i.e. in such combinations as $S_1S_2 \times S_1S_3$ discussed later in this paper. As a source of differences of yield such a possibility cannot be entirely precluded.

The effect of degrees of generational sterility in the Sweet Cherry and other cultivated fruits is commonly evident in the proportion of good seeds which form. In cherries it is rare for both of the ovules in the ovary to develop and form good seeds ; in certain varieties of plums, however, two seeds commonly form, and as many as 40% have been found to develop two viable seeds (Crane 1920). At the beginning of these experiments the seeds were not always examined, but in recent years they have been recorded in some detail and the results are given in Table III.

The seeds recorded as bad were all very poorly developed, and in most cases little more than an empty testa remained at the time of examination. After the fruits were fully ripe the stones were removed and stratified in pots in sterilized sand, and were kept in a moist condition. Care was taken that they did not become too dry or too wet. The second or third week in the following year the stones were opened and examined ; germination had usually begun by this time. In Table III it will be seen that out of a total of 17,939 stones examined 11,355 seeds were obtained. Only twenty stones contained two seeds each. The seeds recorded as good varied to some extent ; a proportion had a slight depression or sunken area, usually at the apical end. The

TABLE III.

Variety.	Cross-compatible Pollinations.			Seed Content.		
	Flowers.	Fruit.	%	Stones.	Seeds.	%
Baumann's May	69	5	7·2	4	2	50·0
Bedford Prolific	7,969	2,774	34·8	1,782	967	54·3
Belle Agathe	3,240	992	30·6	715	650	90·8
,, de Orleans	3,441	604	17·5	316	67	21·2
Big. Gaucher	125	30	24·0	30	30	100·0
,, Jaboulay	1,331	323	24·2	98	31	31·6
,, Kentish	6,830	1,183	17·3	680	525	77·2
,, Ludwigs	798	150	18·8	108	73	67·6
,, Napoleon	6,172	1,855	30·0	1,060	745	70·3
,, Schrecken	11,350	2,415	21·3	1,121	707	63·1
Black Circassian	22	8	36·3	8	1	12·5
,, Cluster	307	135	43·9	103	72	69·9
,, Downton	212	55	25·9	33	0	0·0
,, Eagle	2,094	425	20·3	216	47	21·8
,, Elton	233	75	32·2	61	2	3·3
,, Heart	471	107	22·7	9	1	11·1
,, Heart "B"	389	77	19·8	11	3	27·3
,, Oliver	72	46	63·9	26	6	23·1
,, Tartarian "A"	2,452	241	9·8	119	13	10·9
,, Tartarian "B"	802	164	20·4	9	0	0·0
,, Tartarian "D"	658	181	27·5	154	24	15·6
,, Tartarian "E"	331	57	17·2	23	10	43·5
Bohemian Black	5,224	1,231	23·5	758	601	79·3
Cryall's Seedling	64	33	51·6	31	19	61·3
Early Purple Gean	617	132	21·4	102	24	23·5
Early Rivers	5,373	1,389	25·8	928	607	65·4
Elton Heart	2,508	725	29·0	558	223	39·9
Emperor Francis	5,490	1,193	21·7	738	525	71·1
Florence	1,184	503	42·5	299	231	77·2
Frogmore Early	5,717	1,757	30·5	1,187	608	51·2
Géante de Hedelfingen	3,169	813	25·6	767	688	89·6
Goodneston Black	44	31	70·4	27	28	100·0+
Governor Wood	4,082	1,471	36·0	759	220	28·9
Guigne d'Annonay	1,515	786	51·9	428	153	35·7
Ham Green Black	223	141	63·2	135	110	81·4
Knight's Early Black	838	222	26·4	83	49	59·0
Late Black Big.	3,701	1,121	30·2	691	560	81·0
Monstrueuse de Mezel	1,667	552	33·1	294	229	77·8
Mumford Black	270	48	17·8	10	1	10·0
Noble	3,617	1,042	28·8	855	617	72·1
Noir de Guben	2,008	925	46·2	407	333	81·8
Noir de Schmidt	4,381	780	17·8	449	256	56·9
Ohio Beauty	104	7	6·7	7	7	100·0
Peggy Rivers	950	319	33·5	301	285	94·7
Preserving	114	92	80·7	75	73	97·3
Red Turk	225	84	37·3	12	9	75·0
Roundel Heart	444	150	33·7	107	30	28·0
Smoky Dunn	161	45	27·9	40	8	20·0
Stark's Gold	1,648	377	22·9	350	301	86·0
Turkey Heart	3,387	658	19·4	375	263	70·1
Ursula Rivers	1,344	304	22·5	204	190	93·0
Victoria Black	508	72	14·2	14	11	78·0
Waterloo	1,920	371	19·3	217	127	58·5
Yellow Spanish	31	4	12·9	4	2	50·0

majority were plump and, from external appearances, well developed; but of the total seeds sown the average germination was only 58·4%.

In a recent paper Tukey (1933) makes the general statement that "Early-ripening varieties of Sweet Cherry should not be used as female parents in the breeding of new varieties. Breeding records involving late-ripening and early-ripening varieties of cherries show no progeny when early-ripening varieties are used as female parents, but do show progeny when used as male parents, indicating that the problem of production of non-viable seed is not genetic." That late-ripening cherries may develop a larger proportion of apparently good seeds may in some cases be true, but even this is not a universal rule, as can be seen from Table IV.

Table IV.

Variety.	No. of Seeds sown.	No. germinated.	Percentage of germination.
Early Purple Gean	19	18	94·7
Early Rivers	93	62	66·6
Frogmore Early	186	90	48·3
Knight's Early Black	38	16	42·1
Governor Wood	65	25	38·4
Bedford Prolific	258	182	70·5
Big. Kentish	113	63	55·7
Big. de Schrecken	196	113	57·6
Elton Heart	42	24	57·1
Emperor Francis	82	45	54·8
Géante de Hedelfingen	186	148	74·2
Late Black Big.	39	20	51·2
Montrueuse de Mezel	16	9	56·2
Stark's Gold	140	87	62·1
Ursula Rivers	93	89	95·6
Waterloo	81	63	77·7
Big. Gaucher	21	19	93·8
Big. Napoleon	199	157	78·8
Bohemian Black	27	17	62·9
Florence	182	120	65·9
Noble	283	74	26·1
Noir de Schmidt	142	35	24·6
Total	2,483	1,476	59·4

It is also shown in this Table that early-ripening varieties have developed good seeds. Some of these were sown, and the proportion which germinated is shown in Table IV, which includes details of a number of both early and late-ripening varieties. The first five varieties in this Table, i.e. Early Purple Gean to Governor Wood, are early-ripening varieties. At the other extreme, Florence, Big. Gaucher and Noble are late-ripening varieties.

We have previously pointed out that degrees of sterility are more likely to be reflected on the female than on the male side, owing to the fact that there are only two female to almost innumerable male germ-cells in each flower; and the statement that "The problem of production of non-viable seed is not

genetic" is far too wide an assertion. This statement cannot be accepted as a generalization in the Sweet Cherries any more than it can be accepted and applied to plants in general. On the contrary, our results show that, although sterility is an involved and complex problem, its complexity has a genetic and hereditary basis. The same variety of cherry when used as female and pollinated with different varieties often varies considerably in the proportion of seeds formed. Such differences have varied from 100 to 0% of apparently good seeds; and since these differences have occurred on trees under identical conditions, and often on the same tree, it is more likely that they are due to genetic causes than directly and entirely to nutritional or other environmental causes.

Among a number of the families raised, albino and albinotic variegated seedlings have occurred. Details are given in Table V (see also Fig. 4). The albinos, and most of the variegated seedlings, die at an early stage, and it is probable, apart from the occurrence of these non-viable seedlings, that genetic factors may in certain cases affect the development of the embryo and give rise to non-viable seeds.

TABLE V.

Parents.		Number of Seeds sown.	Number Germinated.	Percentage Germinated.	Number of Albinos.	Number Variegated.
Big. Gaucher	× Knight's Early Black ..	21	19	90·5	2	—
,, Napoleon	× Géante de Hedelfingen ..	19	14	73·6	3	—
,, ,,	× Ursula Rivers	20	9	45·0	5	—
,, ,,	× Ursula Rivers	12	10	83·3	1	—
Florence	× Géante de Hedelfingen ..	53	41	77·3	4	5
,,	× Noir de Schmidt	16	9	56·2	2	—
Géante de Hedelfingen	× Big. Jaboulay	26	17	65·4	—	3
,, ,,	× Ursula Rivers	70	40	57·1	13	—
Late Black Big.	× Big.Gaucher	24	7	29·1	2	—
Monstrueuse de Mezel	× Florence	16	9	56·2	—	1
Noble	× Noir de Schmidt	33	11	33·3	2	—
Ursula Rivers	× Géante de Hedelfingen ..	55	35	63·6	9	—
Waterloo	× Florence	35	20	57·1	—	6

As far as the formation and development of fruit is concerned the total results obtained from pollinating Sweet varieties with varieties of the Sour Cherries are not far below those obtained from compatible pollinations of Sweet with Sweet. The results are 20 and 22·5% respectively (see Table II). But where the Duke varieties were used, an appreciably less proportion of fruit developed, i.e. 15·1%. This is undoubtedly attributable to the higher degree of sterility of the Duke Cherries, which results from their hybrid origin and is characteristic of the Duke group. As expressed by aborted pollen grains

and the proportion which germinate, it is shown in Table VI that, although there is a considerable range of variation in the degree of sterility within both the Sweet and Duke Cherries, it is in all cases much higher in the Duke varieties. The pollen germination tests detailed in Table VI were made on agar as a medium, and different concentrations of cane sugar were used, ranging from 5 to 12%. In some cases a slightly higher proportion germinated in the 12% cane sugar, in others the proportion was slightly higher in 5%, but in all cases the differences were very small. In a previous paper (Crane and Lawrence 1929) it was shown that in the reciprocal pollinations, Sour by Sweet and Dukes by Sweet, a much smaller proportion of fruit was obtained, namely 8·1 and 5·3 respectively. The number of flowers used in these pollinations was not very extensive, the actual figures being:—

Sour by Sweet, flowers pollinated 1,144; fruits set 93;
Dukes by Sweet, ,, ,, 2,406; ,, ,, 129.

Since then, 2,400 additional pollinations have been made, and the total proportion of fruit which set remains approximately the same. Amongst these pollinations, however, considerable variations occurred. A 20% set or over was obtained in a very few cases. The majority gave less than 10%, and a few failed entirely. In the cases of failure the numbers were not high enough to determine whether or not such failure was due to incompatibilty.

We have previously pointed out that the differences obtained from these reciprocal pollinations may arise from difficulties in endosperm formation, as,

Table VI.

Varieties.	No. of Pollen grains examined.	No. of Pollen grains germinated.	No. of aborted Pollen grains.	Percentage of germination.
Bedford Prolific	1,898	1,845	53	97·2
Belle Agathe	1,112	959	153	86·2
Big. Napoleon	1,214	905	309	74·6
Big. Schrecken	921	623	298	67·6
Black Eagle	1,908	1,473	435	77·2
Black Tartarian "A" ..	1,058	583	475	55·1
Early Rivers	1,639	1,345	304	82·6
Emperor Francis	1,481	1,273	208	85·9
Governor Wood	1,084	980	104	90·4
Guigne d'Annonay	590	563	27	95·4
Knight's Early Black	618	531	87	85·9
Noir de Schmidt	1,507	746	761	49·2
Waterloo	1,098	936	162	85·2
Duke Cherries:				
Archduke	972	78	714	9·8
Empress Eugenie	1,213	331	882	27·3
Late Duke	894	132	762	14·8
May Duke	1,595	223	1,372	13·8
Reine Hortense	1,359	451	908	33·2

following triple fusion, the endosperm of the tetraploid Duke and Sour Cherries when pollinated by the diploid Sweet Cherries will be pentaploid, or approximately so. But in the reciprocal pollinations, where the Sweet Cherries are used as females, the endosperm will be tetraploid. Possibly the endosperm of pentaploid constitution may have greater developmental difficulties than the tetraploid endosperm, and this may be the cause of the lower yield where the tetraploid Sour Cherries are used as females, and the differences in the proportion of fruit set in the reciprocal pollinations between these groups.

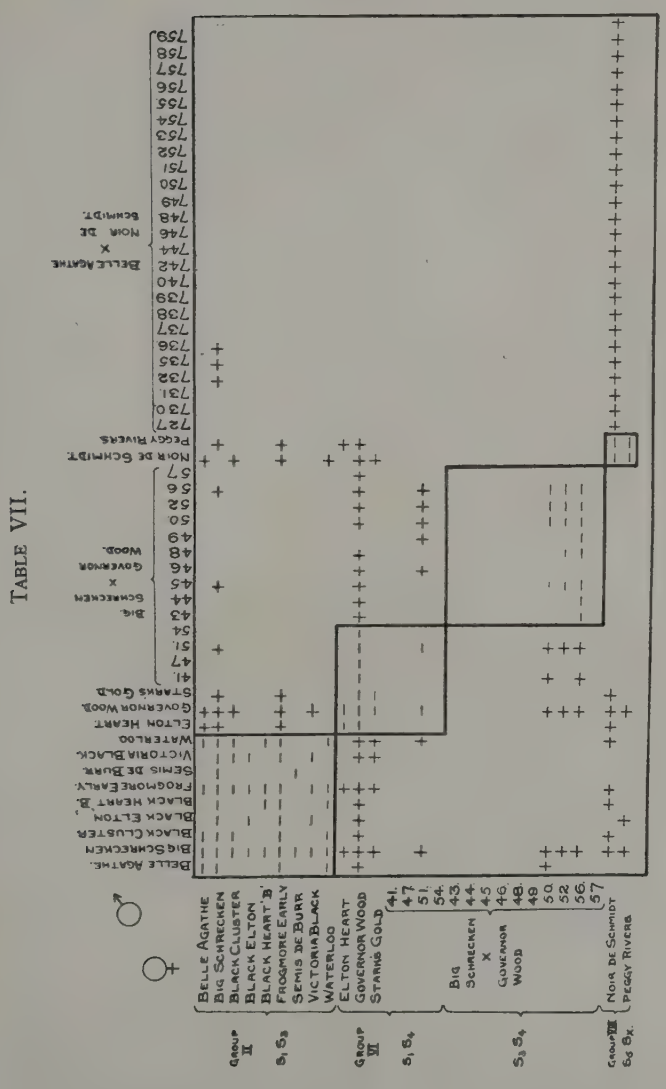
THE VARIETAL BEHAVIOUR AND HEREDITARY BASIS OF INCOMPATIBILITY.

In a previous paper (Crane and Lawrence 1930) we published some preliminary results and concluded that the hereditary basis of incompatibility in the Sweet Cherry was amenable to the oppositional factor hypothesis advanced by East and Mangelsdorf (1925) from their extensive work on Nicotiana, and subsequently found to apply to many other plants. We have continued to make a factorial analysis of the hereditary and varietal behaviour of incompatibility by determining the behaviour of pollinations among the progeny of inter-group crosses, and from pollinations between them and their parents. Some of the results obtained are given in Table VII. They show that the progeny raised from Belle Agathe (Group II) crossed Noir de Schmidt (Group VIII) are all effective on their male parent, whilst the progeny from Big. de Schrecken (Group II) crossed Governor Wood (Group V) form two intra-sterile, inter-fertile groups, one of which fails with its male parent. Details of the pollinations recorded in Table VII are: compatible pollinations, flowers 5,134, fruits set 1,153, $=22{\cdot}4\%$; incompatible pollinations, flowers 5,930, fruits set 5, $=0{\cdot}08\%$.

Incompatibility is determined by genetic factors which control pollen-tube growth, and the essential feature of the genetic behaviour of incompatibility is that under normal conditions pollen cannot function in the style of a plant carrying the same factors as the pollen. These factors form a multiple series of allelomorphs, and any two of them may be carried by a given plant. Thus, following East's and Mangelsdorf's terminology, effective and non-effective pollinations arise as follows:—

Male germ cells =		$S_1S_2 \times S_1S_2$		$S_1S_2 \times S_3S_4$		$S_1S_2 \times S_1S_3$	
		S_1	S_2	S_3	S_4	S_1	S_3
Female tissue (Female germ-cells.)	S_1	fail	fail	S_1S_3	S_1S_4	fail	S_1S_3
	S_2	fail	fail	S_2S_3	S_2S_4	fail	S_2S_3

TABLE VII.


♀
♂
Belle Agathe
Big Schrecken
Black Cluster
Black Elton
Black Heart 'B'
Frogmore Early
Semis de Burr
Victoria Black
Waterloo
Elton Heart
Governor Wood
Starks Gold
Big Schrecken × Governor Wood
Noir de Schmidt
Peggy Rivera
Group II
S1 S3
Group VI
S1 S4
S3 S4
Group VII
S3 S4
41
47
51
54
43
44
45
46
48
49
50
52
56
57
Belle Agathe × Noir de Schmidt
742
744
746
748
749
750
751
752
753
754
755
756
757
758
759
730
731
732
735
736
737
738
739
740
727
(+ = compatible ; − = incompatible.)

The offspring from $S_1S_2 \times S_3S_4$ will fall into four incompatible groups and those from $S_1S_2 \times S_1S_3$ into two. All the seedlings in the former cross will be reciprocally compatible with their parents, as in the family raised from Belle Agathe × Noir de Schmidt. In the latter cross, however, the S_1S_3 group will be reciprocally incompatible with its male parent, as occurred in the family from Big. de Schrecken × Governor Wood, for they carry the same factors. All other combinations between parents and the F_1 generation will be effective, as they differ in at least one respect. A number of other seedlings, raised from different inter-group crosses, have been used in similar tests. They have usually comprised small units of about six sister-seedlings, and consequently the details could be given only at considerable length ; but in all cases the results obtained have been in agreement with the above factorial scheme. These recent results, therefore, substantiate our earlier conclusions, and they are also beginning to show the genetic constitution and relationship of the established varieties investigated and the groups to which they belong. Amongst the Sweet Cherries in cultivation we have tested 66 varieties. They fall into 11 groups, and in addition 21 varieties remain independent (see Table I). Therefore, at least 32 different combinations and a minimum of 9 incompatibility factors are necessary to interpret the results so far obtained.

As shown in Table IX, a few fruits have been obtained both from selfing and from cross-incompatible pollinations, but very few of these fruits have developed perfect seeds, and the majority have been non-viable. Possibly some of these fruits are the results of accident, but some have set under very stringent conditions, which suggests that, as a rarity, a pollen-tube travels the full length of the style and effects fertilization. One of the seedlings which arose in these experiments in this way, No. 500, came from Big. Frogmore × Big. de Schrecken, co-incompatibles in Group II. The results of pollinations made between this seedling and its parents are as follows:—

Big. Frogmore × No. 500 (1932)	..	Flowers 66	Fruits 0
,, ,, × ,, ,, (1933)	..	,, 16	,, 0
	Total	,, 82	,, 0
Big. de Schrecken × No. 500 (1932)	..	,, 49	,, 0
,, ,, ,, × ,, ,, (1933)	..	,, 30	,, 0
	Total	,, 79	,, 0

We have provisionally designated the genetic constitution of Group II as S_1S_3. Therefore, if fertilization occurred within this group it would give rise either to plants of the same constitution as the parents, e.g. S_1S_3, or to homozygous

plants, S_1S_1 or S_3S_3. Those of the same constitution would reciprocally fail with their parents. The homozygous derivatives would be effective when used as females, but would also fail when used as males in pollinations with their parents. The results of the pollinations made between Big. Frogmore, Big. de Schrecken and seedling No. 500 are therefore in agreement with the view that the seedling arose from fertilization between co-incompatible varieties. Seedling No. 500, although of healthy growth, lacks vigour and is only about half the size of trees of the same age raised from parents which are normally compatible.

Among the established varieties of the Sweet Cherry investigated, cross-incompatibility has always been reciprocally expressed; that is to say, if A fails with B, it has always followed that B failed with A. It is theoretically possible for varieties to originate which would be compatible in one direction of a cross and fail in the other, e.g. homozygous varieties such as S_1S_1, etc.; but if the lack of vigour of seedling No. 500 is also characteristic of such individuals, they are unlikely to be grown commercially or to receive varietal recognition.

VARIETAL CONFUSION.

Considerable confusion prevails in the varietal nomenclature of cherries; different individuals are frequently distributed under one varietal name, and to find an individual under two or more names is also common. Many of the varieties we have investigated are widely cultivated and are to be found in almost any district where cherries are grown; but the cultivation of others is more restricted and some appear to be confined to local areas.

As far as we have been able to determine, all the varieties we have investigated are distinct individuals, but the identity of some is obscure and still under investigation. It will be noted in Tables I and IX that four individuals, designated "A", "B", "D" and "E", bear the name of Black Tartarian. All these individuals have black-coloured fruits, but they differ in such characters as the size, shape and pigmentation of leaves and flowers, and are quite distinct. Black Heart is also different from Black Heart "A". Trees referred to in a previous paper as Windsor "A" and Mezel "A" were purchased as Windsor and Mezel respectively, but both were eventually found to be Big. Napoleon. Of other trees obtained under the name of Monstrueuse de Mezel, some have completely failed on Géante de Hedelfingen, while others have effectively pollinated this variety. They therefore appear to be different individuals. We have used comparatively few varieties of the Sour Cherries in pollinations with Sweet Cherries, but even in the few used, similar difficulties have occurred. Trees obtained under the name of Morello have differed in minor respects, and,

as detailed in an earlier report, Kentish Red and Kentish Red " A " are distinct ; the former is self-incompatible and has comparatively long pedicels, whilst Kentish Red " A " is self-compatible and has short pedicels.

We are indebted to Mr. N. H. Grubb for a number of the varieties we have used, particularly the local varieties, and also for much valuable information concerning the identity of varieties, obtained during visits to the East Malling Research Station over a period of years.

THE INTERPLANTING OF VARIETIES.

Although many factors such as disease, nutrition, climatic conditions, etc., affect the initial setting of the fruit and the ultimate yield, the results of the present experiments show that effective pollination and fertilization is a first essential for the formation and development of the fruits of cherries. Therefore, since self-incompatibility appears to be general throughout the Sweet Cherries and cross-incompatibility common, it is important to ensure that adequate provision is made for effective cross-pollination.

No variety of the Sweet Cherry should be planted in complete isolation either as single trees in private gardens or as large blocks in commercial plantations ; and care should be taken to interplant varieties which are known to be compatible and which flower at the same time.

Knowledge of the relative flowering times of cherries in cultivation is far from complete, and nothing appears to be known precisely about alleged fluctuations of this character ; but two recent publications, Hooper (1932) and Beakbane, Chapelow and Grubb (1935), deal specially with this subject and provide much valuable information. The latter investigators state that early and late blossoming varieties do not overlap enough in season for effective cross-pollination, and in planning a cherry orchard, this fact, as well as that of cross-incompatibility, must be allowed for. They also show that varieties differ in the length of their blossoming period, and also in the relative position of their times of full bloom.

The relative flowering times as given by Hooper do not in all cases agree with those given by Beakbane and her collaborators, indeed in some cases they differ considerably. The records of the blossoming period by Beakbane *et al.* were made at the East Malling Research Station from two sets of trees, one planted in 1921 and the other in 1926, and their average period of blossoming and time of full bloom is given for six and four years respectively. In Table VIII we have attempted, as far as the details will allow, to co-ordinate their results with our work on incompatibility. In this Table the relative time of full bloom is given, and co-incompatible varieties and the group to which they belong are indicated by the Roman numeral.

Table VIII.

Varieties of the Sweet Cherry, in order of time of full bloom.

Ham Green Black	
Early Cluster	
Guigne d'Annonay (XI)	
Noir de Guben	
Cryall's Seedling (XI)	
Red Turk (IX)	
Baumann's May (I)	April 21st to 27th.
Black Tartarian "E"	
Turkey Heart (V)	
Bedford Prolific (I)	
Black Heart "B" (II)	
Black Oliver	
Early Rivers (I)	
Belle Agathe (II)	
Big. Ludwigs (IV)	
Black Eagle (I)	April 27th to May 1st.
Waterloo (II)	
Preserving	
Ohio Beauty (III)	
Knight's Early Black (I)	
Black Circassian (I)	
Roundel Heart (I)	
Elton Heart (VI)	
Black Cluster (II)	May 1st to 8th.
Victoria Black (II)	
Governor Wood (VI)	
Big. Kentish (IV)	
Frogmore Early (II)	
Large Black	

In addition to the varieties of Sweet Cherry given in this Table, Hooper gives the following:—

Early flowering: Early Purple Gean, Goodneston Black.

Mid-season flowering: Monstrueuse de Mezel (VIII), Big. Jaboulay (X), Noir de Schmidt (VIII), Big. de Schrecken (II).

Late flowering: Big. Napoleon (III), Florence, Noble, Géante de Hedelfingen (VII).

(The Roman numerals show co-incompatibles, as in the above Table.)

In their report, Beakbane *et al.* also give the time of full bloom of a number of varieties of the Sour and Duke Cherries as follows:—

Royal Duke May Duke Wye Morello Kentish Red "A"	April 29th to May 5th.
Morello Archduke Carnation Late Duke	May 5th to 12th.

Hooper gives Empress Eugenie and Flemish Red as late flowering varieties.

ACKNOWLEDGMENTS.

From 1924 to 1932 Mr. W. J. C. Lawrence took part in these experiments, and Mr. R. J. Gutsell did so from 1932 to 1934. We are also indebted to several students from Studley College for assistance in the work of emasculation and pollination of cherries and other fruits in the years 1931-4. Mr. S. G. Smith, now at McGill University, Montreal, also gave assistance in 1930. The work on pollen germination summarized in Table VI was mainly done by him. During 1936 Dr. A. C. Fabergé and Mr. D. Lewis took part in the work.

SUMMARY.

In this paper the results obtained from over 236,000 pollinations of cherries are described. In the Sweet Cherry self-incompatibility was found to be the rule, cross-incompatibility common and always reciprocally expressed. Out of a total of 66 varieties investigated, 45 were found to belong to 11 incompatible groups, within which all self- and cross-pollinations fail.

An analysis of investigations with seedlings shows that incompatibility in the Sweet Cherry is an orderly phenomenon, and the results, as far as they go, are in agreement with the oppositional factor hypothesis advanced by East and Mangelsdorf for Nicotiana.

Incompatibility in the Sweet Cherry is expressed by the young fruits ceasing to grow and falling from the tree at an early stage. It is due to the pollen-tubes being arrested in their growth down the stylar tissue, hence fertilization cannot take place and the fruit fails to develop.

Degrees of generational sterility occur and are expressed by aborted pollen, imperfectly developed or non-viable seeds and occasionally by differences in the proportion of fruits which set and reach maturity.

Since cross-incompatibility is of common occurrence in the Sweet Cherry, the interplanting of suitable varieties, so that provision is made for effective cross-pollination, is of the first importance. When making the provision both compatibility and the time of flowering of varieties must be considered.

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Table IX.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Baumann's May.			
Selfed	89	0	0
Bedford Prolific	13	0	0
Early Rivers	78	1	1
Ronald's Heart	45	0	0
Big. Schrecken	44	2	4
Black Elton	6	1	17
West Midlands Big.	19	2	10
Bedford Prolific.			
Selfed	2,020	0	0
Baumann's May	161	1	1
Black Downton	361	0	0
Black Eagle	313	0	0
Black Tartarian A	207	0	0
Black Tartarian B	158	0	0
Early Rivers	1072	0	0
Knight's Early Black	354	0	0
Leicester Black	44	1	2
Roundel Heart	428	0	0
Belle Agathe	424	102	24
Belle d'Orléans	163	65	40
Big. Jaboulay	40	4	10
Big. Ludwigs	45	5	11
Big. Napoleon	1,077	374	35
Big. Schrecken	414	134	32
Black Cluster	273	72	26
Black Elton	428	61	14
Black Heart B	168	61	36
Black Oliver	229	66	29
Black Tartarian E	98	53	54
Bohemian Black	95	66	69
Early Purple Gean	41	17	41
Elton Heart	26	21	81
Emperor Francis	671	231	34
Frogmore Early	501	192	38
Géante de Hedelfingen	39	6	15
Goodneston Black	154	115	75
Governor Wood	249	162	65
Ham Green Black	34	18	53
Late Black Big.	118	58	49
Monstrueuse de Mezel B	184	85	46
Noble	36	23	64
Noir de Guben	40	4	10
Noir de Schmidt	128	25	19
Ohio Beauty	57	24	42
Peggy Rivers	71	29	41
Red Turk	139	67	48
Semis de Burr	33	9	27
Smoky Dunn	46	20	43
Stark's Gold	537	169	31
Turkey Heart	131	93	71
Ursula Rivers	304	169	56
Victoria Black	64	7	11
Waterloo	273	96	35
White Big.	125	41	33
Yellow Spanish	86	24	28
Carnation*	32	2	6
May Duke*	27	13	48
Prunus decumana	12	1	8
Beeve's Heart.			
Selfed	22	0	0
Big. Napoleon	30	1	3
Belle Agathe.			
Selfed	1,281	0	0
Big. Schrecken	923	0	0
Black Cluster	35	1	2
Frogmore Early	897	0	0
Waterloo	550	1	0
Bedford Prolific	248	124	50
Belle d'Orléans	158	24	15
Big. Jaboulay	47	31	66
Big. Kentish	152	20	13
Big. Ludwig's	138	14	10
Big. Napoleon	131	64	49
Black Eagle	226	17	7
Black Tartarian A	32	17	53
Black Tartarian B	70	12	17
Black Tartarian E	52	2	4
Bohemian Black	316	59	19
Early Purple Gean	24	7	29
Early Rivers	51	9	18
Elton Heart	224	33	15
Emperor Francis	221	61	28
Géante de Hedelfingen	57	23	40
Governor Wood	49	23	47
Knight's Early Black	90	16	18
Late Black Big.	119	16	13
Monstrueuse de Mezel B	132	29	22
Noble	196	22	11
Noir de Guben	166	59	35
Noir de Schmidt	146	74	51
Roundel Heart	18	8	44
Turkey Heart	177	12	7
White Big.	177	62	35
May Duke*	197	28	14
Prunus decumana	18	7	39
Belle d'Orléans.			
Selfed	3081	1	0
Bedford Prolific	28	8	29
Belle Agathe	59	9	15
Big. Gaucher	73	12	16
Big. Jaboulay	89	29	33
Big. Kentish	138	12	9
Big. Napoleon	97	18	18
Big. Schrecken	775	45	5
Black Cluster	83	18	22

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Black Tartarian A	46	18	39
Bohemian Black	103	8	8
Cryall's Seedling	198	43	22
Early Rivers	67	13	19
Elton Heart	221	54	24
Emperor Francis	239	4	17
Florence	79	15	19
Frogmore Early	12	2	17
Governor Wood	98	27	27
Guigne d'Annonay	125	35	28
Knight's Early Black ..	28	13	46
Large Black	159	56	35
Late Black Big.	198	23	12
Monstrueuse de Mezel B ..	59	17	29
Mumford Black	196	53	27
Noble	44	11	25
Noir de Guben	108	32	30
Noir de Schmidt	15	6	40
Preserving	122	23	19
Bigarreau Gaucher.			
Selfed	*103*	*0*	*0*
Big. Napolean	7	3	42
Big. Schrecken	70	6	9
Knight's Early Black ..	48	21	44
Bigarreau Jaboulay.			
Selfed	*709*	*1*	*0*
Black Tartarian D ..	*24*	*0*	*0*
Bedford Prolific	52	32	61
Belle Agathe	87	39	45
Belle d'Orléans	57	6	10
Big. Napoleon	37	8	22
Black Heart B	37	9	24
Black Tartarian B	18	13	72
Bohemian Black	76	10	13
Early Purple Gean ..	48	16	33
Early Rivers	105	14	13
Emperor Francis	30	4	13
Florence	126	9	7
Frogmore Early	24	18	75
Géante de Hedelfingen ..	37	8	22
Knight's Early Black ..	39	9	23
Late Black Big.	93	21	22
Leicester Black	14	2	14
Noble	49	15	31
Noir de Guben	138	34	25
Noir de Schmidt	82	24	29
Peggy Rivers	74	7	9
Roundel Heart	34	13	38
Waterloo	21	6	28
White Big.	29	3	10
Archduke*	24	0	0
May Duke*	202	3	1
Royal Duke*	134	12	9
Kentish Red*	16	8	50
Reine Hortense*	26	2	8

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Bigarreau Kentish.			
Selfed	*1,152*	*0*	*0*
Big. Ludwig's	*145*	*0*	*0*
White Big.	*608*	*0*	*0*
Yellow Spanish	*49*	*0*	*0*
Baumann's May	119	14	12
Bedford Prolific	275	23	8
Belle Agathe	89	11	12
Big. Gaucher	37	6	16
Big. Jaboulay	30	9	30
Big. Napoleon	1,189	215	18
Big. Schrecken	214	31	14
Black Downton	109	6	5
Black Eagle	72	16	22
Black Elton	123	12	10
Black Heart B	71	15	21
Black Oliver	98	27	31
Black Tartarian D ..	236	46	19
Bohemian Black	943	93	10
Early Rivers	228	37	16
Florence	140	21	15
Géante de Hedelfingen ..	228	28	12
Goodneston Black	241	60	24
Guigne d'Annonay	930	184	20
Ham Green Black ..	100	18	18
Mumford Black	127	38	30
Noir de Guben	25	8	32
Noir de Schmidt	287	60	21
Peggy Rivers	42	9	21
Red Turk	102	15	15
Ronald's Heart	67	13	19
Smoky Dunn	142	5	3
Turkey Heart	86	27	31
Ursula Rivers	385	106	27
Victoria Black	95	4	4
Archduke*	156	26	17
Late Duke*	91	21	23
May Duke*	235	3	1
Royal Duke*	37	5	13
Carnation*	204	3	1
Kentish Red*	68	6	9
Morello*	491	26	5
Wye Morello*	61	9	15
Prunus decumana	154	42	27
Bigarreau Ludwig's.			
Selfed	*209*	*0*	*0*
Big. Kentish	*66*	*0*	*0*
White Big.	*54*	*0*	*0*
Bedford Prolific	79	15	19
Belle d'Orléans	23	6	26
Big. Jaboulay	44	15	34
Big. Napoleon	61	18	29
Black Cluster	97	7	7
Elton Heart	51	11	21
Emperor Francis	114	17	15
Knight's Early Black ..	128	23	18

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Monstrueuse de Mezel B ..	27	6	22
Noble	7	1	14
Noir de Schmidt	13	4	31
Waterloo	154	27	18
BIGARREAU NAPOLEON.			
Selfed	*1,429*	*2*	*0*
Emperor Francis	*1,350*	*1*	*0*
Ohio Beauty	*27*	*0*	*0*
Baumann's May	169	30	18
Bedford Prolific	114	56	49
Belle Agathe	186	77	41
Belle d'Orléans	186	63	34
Big. Gaucher	192	15	8
Big. Jaboulay	41	13	32
Big. Kentish	98	38	39
Big. Ludwig's	222	19	8
Big. Schrecken	143	76	53
Black Cluster	33	20	61
Black Downton	65	17	26
Black Eagle	170	44	26
Black Elton	98	25	25
Black Heart B	119	50	42
Black Oliver	90	12	13
Black Tartarian A ..	50	32	64
Black Tartarian B ..	71	47	66
Black Tartarian D ..	174	44	25
Bohemian Black	50	33	66
Cryall's Seedling	61	21	34
Early Purple Gean ..	54	33	61
Early Rivers	77	44	57
Elton Heart	20	4	20
Florence	104	28	27
Frogmore Early	82	21	26
Géante de Hedelfingen ..	202	74	37
Goodneston Black	146	31	21
Governor Wood	65	35	54
Guigne d'Annonay	422	137	31
Ham Green Black ..	154	26	17
Knight's Early Black ..	92	41	44
Large Black	50	5	10
Late Amber	42	6	14
Late Black Big.	203	73	36
Monstrueuse de Mezel B ..	153	43	28
Mumford Black	44	6	14
Noble	301	48	16
Noir de Guben	44	17	39
Noir de Schmidt	483	151	31
Peggy Rivers	51	10	20
Preserving	80	4	5
Red Turk	143	47	33
Ronald's Heart	30	2	7
Roundel Heart	36	19	53
Semis de Burr	31	3	10
Smoky Dunn	43	4	9
Stark's Gold	295	51	18
Turkey Heart	88	9	10
Ursula Rivers	109	40	37
Victoria Black	36	4	11
Waterloo	56	36	65
White Big.	75	32	42
Yellow Spanish	29	2	7
Archduke*	13	2	15
Empress Eugenie* ..	31	24	77
Late Duke*	22	4	18
May Duke*	16	11	69
Royal Duke*	26	10	38
Carnation*	75	4	5
Kentish Red*	20	11	55
Wye Morello*	28	6	21
BIGARREAU SCHRECKEN.			
Selfed	*3,286*	*0*	*0*
Belle Agathe	*961*	*3*	*0*
Black Cluster	*161*	*0*	*0*
Black Elton	*171*	*1*	*0*
Black Heart B	*103*	*1*	*1*
Frogmore Early	*2,884*	*1*	*0*
Semis de Burr	*32*	*0*	*0*
Victoria Black	*162*	*0*	*0*
Waterloo	*207*	*1*	*0*
Baumann's May	58	6	10
Bedford Prolific	1,073	203	20
Beeve's Heart	49	3	6
Belle d'Orléans	263	71	27
Big. Jaboulay	246	71	28
Big. Kentish	644	94	15
Big. Ludwig's	419	50	12
Big. Napoleon	596	160	27
Black Downton	50	2	4
Black Eagle	117	42	36
Black Heart	109	46	42
Black Oliver	122	9	7
Black Tartarian B ..	264	57	22
Black Tartarian E ..	60	28	47
Bohemian Black	173	29	17
Cryall's Seedling	327	45	14
Early Purple Gean ..	429	114	26
Early Rivers	1,069	283	26
Elton Heart	100	26	26
Emperor Francis	552	103	19
Florence	106	32	30
Géante de Hedelfingen ..	146	31	22
Goodneston Black	175	20	11
Governor Wood	245	53	21
Guigne d'Annonay	71	29	41
Ham Green Black ..	29	10	35
Knight's Early Black ..	195	59	30
Late Amber	56	11	20
Late Black Big.	286	55	19
Leicester Black	65	8	12
Monstrueuse de Mezel B ..	473	98	21
Mumford Black	122	4	3
Noble	43	15	35

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Noir de Guben	501	162	32
Peggy Rivers	96	7	7
Preserving	164	8	5
Red Turk	54	4	7
Roundel Heart	151	66	44
Smoky Dunn	162	39	24
Stark's Gold	280	50	18
Turkey Heart	220	44	20
Ursula Rivers	46	8	17
White Big.	694	35	5
Yellow Spanish	79	10	13
Late Duke*	111	22	20
Royal Duke*	671	44	6
Kentish Red*	95	24	25
Morello*	219	57	26
Chinese Early*	101	3	3
Prunus decumana	39	17	43
Black Circassian.			
Selfed	*122*	*0*	*0*
Big. Napoleon	22	8	36
Black Cluster.			
Selfed	*138*	*0*	*0*
Big. Schrecken	*36*	*0*	*0*
Frogmore Early	*14*	*0*	*0*
Victoria Black	*82*	*0*	*0*
Waterloo	*52*	*0*	*0*
Bedford Prolific	31	13	42
Big. Kentish	28	18	64
Big. Napoleon	41	6	15
Early Purple Gean ..	11	9	82
Early Rivers	44	43	98
Governor Wood	76	10	13
Noir de Schmidt	36	11	30
Turkey Heart	40	25	62
Black Downton.			
Selfed	*34*	*0*	*0*
Bedford Prolific	*65*	*0*	*0*
Big. Kentish	56	10	18
Big. Napoleon	156	45	29
Black Eagle.			
Selfed	*942*	*0*	*0*
Bedford Prolific	*228*	*0*	*0*
Black Tartarian A ..	*196*	*0*	*0*
Black Tartarian B ..	*46*	*0*	*0*
Early Rivers	*47*	*0*	*0*
Knight's Early Black ..	*111*	*0*	*0*
Roundel Heart	*146*	*0*	*0*
Belle Agathe	290	34	12
Belle d'Orléans	39	6	15
Big. Jaboulay	47	21	45
Big. Kentish	23	20	87
Big. Ludwig's	122	16	13

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Big. Napoleon	41	10	24
Big. Schrecken	183	21	11
Black Cluster	75	7	9
Black Heart B	68	18	26
Black Tartarian D ..	19	6	31
Bohemian Black	80	12	15
Early Purple Gean ..	185	67	36
Elton Heart	158	50	32
Emperor Francis	129	9	7
Florence	34	10	29
Frogmore Early	45	9	20
Géante de Hedelfingen ..	20	6	30
Governor Wood	84	28	33
Late Black Big.	97	17	17
Monstrueuse de Mezel B ..	35	12	34
Noble	43	8	19
Noir de Schmidt	29	9	31
Ursula Rivers	52	12	23
Waterloo	196	17	9
Archduke*	49	4	8
May Duke*	69	8	12
Royal Duke*	51	11	21
Morello*	50	13	26
Black Elton.			
Selfed	*165*	*0*	*0*
Big. Schrecken	*45*	*1*	*2*
Frogmore Early	*107*	*0*	*0*
Victoria Black	*30*	*0*	*0*
Big. Napoleon	79	39	48
Black Downton	130	25	19
Red Turk	24	11	46
Black Heart.			
Selfed	*82*	*0*	*0*
Big. Schrecken	69	17	25
Early Rivers	131	18	14
Elton Heart	32	7	22
Frogmore Early	177	58	33
Morello*	62	7	11
Black Heart B.			
Selfed	*93*	*0*	*0*
Big. Schrecken	*37*	*0*	*0*
Frogmore Early	*58*	*0*	*0*
Waterloo	*18*	*0*	*0*
Big. Kentish	101	35	35
Big. Napoleon	80	10	12
Black Eagle	24	3	12
Guigne d'Annonay	87	20	23
Noble	97	9	9
Black Oliver.			
Selfed	*77*	*0*	*0*
Bedford Prolific	34	15	44
Big. Schrecken	24	13	54
Black Elton	14	8	30

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Black Tartarian A.			
Selfed	*1,776*	*0*	*0*
Bedford Prolific	*65*	*0*	*0*
Black Eagle	*471*	*0*	*0*
Black Tartarian B	*138*	*0*	*0*
Early Rivers	*797*	*0*	*0*
Knight's Early Black	*31*	*0*	*0*
Roundel Heart	*71*	*0*	*0*
Belle Agathe	509	27	5
Belle d'Orléans	76	7	9
Big. Napoleon	332	26	8
Big. Schrecken	88	13	15
Black Cluster	58	4	7
Black Tartarian D	37	8	22
Black Tartarian E	170	30	18
Emperor Francis	206	17	8
Frogmore Early	277	21	7
Governor Wood	212	29	14
Late Black Big.	182	27	15
Noble	66	12	18
Turkey Heart	150	13	9
Waterloo	89	7	8
Black Tartarian B.			
Selfed	*458*	*0*	*0*
Bedford Prolific	*119*	*0*	*0*
Black Eagle	*24*	*0*	*0*
Black Tartarian A	*40*	*0*	*0*
Early Rivers	*656*	*0*	*0*
Knight's Early Black	*57*	*0*	*0*
Roundel Heart	*63*	*0*	*0*
Belle Agathe	24	6	25
Big. Jaboulay	13	8	61
Big. Napoleon	145	17	12
Big. Schrecken	208	31	15
Black Tartarian E	45	5	11
Elton Heart	102	31	30
Emperor Francis	20	4	20
Frogmore Early	118	23	19
Noir de Guben	58	20	34
Turkey Heart	20	7	35
Waterloo	49	12	24
Black Tartarian D.			
Selfed	*115*	*0*	*0*
Big. Jaboulay	*106*	*0*	*0*
Baumann's May	40	5	12
Big. Kentish	41	20	49
Big. Napoleon	26	8	31
Black Heart B	44	17	39
Black Oliver	137	18	13
Florence	23	2	9
Frogmore Early	27	15	56
Goodneston Black	139	32	24
Monstrueuse de Mezel	42	23	55
Noir de Schmidt	32	12	37
Red Turk	51	22	46
Smoky Dunn	56	7	12
Black Tartarian E.			
Selfed	*303*	*0*	*0*
Belle Agathe	41	16	39
Big. Napoleon	38	6	16
Black Tartarian A	86	8	9
Black Tartarian B	15	5	33
Early Rivers	64	10	16
Frogmore Early	17	1	6
Governor Wood	43	5	12
Noir de Schmidt	27	2	7
Bohemian Black.			
Selfed	*1,013*	*3*	*0*
Late Black Big.	*606*	*2*	*0*
Turkey Heart	*586*	*2*	*0*
Bedford Prolific	202	120	56
Belle Agathe	132	23	17
Belle d'Orléans	165	29	18
Big. Jaboulay	325	61	19
Big. Kentish	63	14	22
Big. Ludwig's	198	41	21
Big. Napoleon	355	66	19
Big. Schrecken	261	101	39
Black Eagle	109	21	19
Black Heart B	441	112	25
Black Tartarian A	43	21	49
Black Tartarian D	67	13	19
Cryall's Seedling	118	4	3
Early Purple Gean	169	22	13
Early Rivers	201	90	45
Elton Heart	36	7	19
Emperor Francis	388	66	17
Florence	174	21	12
Frogmore Early	388	80	21
Géante de Hedelfingen	37	29	78
Governor Wood	227	27	12
Guigne d'Annonay	45	7	16
Knight's Early Black	166	48	29
Large Black	34	9	26
Mumford Black	81	8	10
Noble	34	6	17
Noir de Guben	64	20	31
Noir de Schmidt	530	95	18
Peggy Rivers	84	19	23
Preserving	40	5	12
Roundel Heart	57	12	21
Stark's Gold	20	5	25
Ursula Rivers	35	11	31
Waterloo	35	19	54
Archduke*	34	8	23
May Duke*	108	12	11
Royal Duke*	119	24	20
Carnation*	326	20	6
Kentish Red*	461	103	22

* Indicates tetraploid varieties,

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Morello*	52	14	27
Reine Hortense*	35	7	20
Prunus decumana	80	14	17
Cryall's Seedling.			
Selfed	*124*	*0*	*0*
Guigne d'Annonay ..	*14*	*0*	*0*
Big. Napoleon	15	10	67
Big. Schrecken	26	6	23
Peggy Rivers	11	7	64
Turkey Heart	12	10	83
Early Cluster.			
Selfed	*41*	*0*	*0*
Early Purple Gean.			
Selfed	*249*	*0*	*0*
Big. Kentish	87	21	24
Big. Napoleon	119	18	15
Big. Schrecken	131	27	21
Early Rivers	161	35	22
Frogmore Early	4	1	25
Governor Wood	61	10	16
Late Black Big.	14	9	74
Noble	40	11	27
Early Rivers.			
Selfed	*1,340*	*0*	*0*
Baumann's May	*68*	*1*	*3*
Bedford Prolific	*960*	*1*	*0*
Black Circassian	*43*	*0*	*0*
Black Downton	*97*	*0*	*0*
Black Eagle	*590*	*2*	*0*
Black Tartarian A ..	*235*	*0*	*0*
Black Tartarian B ..	*639*	*0*	*0*
Knight's Early Black ..	*339*	*0*	*0*
Roundel Heart	*204*	*0*	*0*
Belle Agathe	122	21	17
Belle d'Orléans	36	4	11
Big. Jaboulay	56	19	34
Big. Kentish	120	17	14
Big. Napoleon	392	87	22
Big. Schrecken	280	40	14
Black Cluster	494	59	12
Black Elton	258	103	40
Black Heart B	391	124	32
Black Oliver	163	58	56
Black Tartarian D ..	56	17	30
Bohemian Black	118	24	20
Early Cluster	29	3	10
Early Purple Gean ..	43	20	46
Emperor Francis	62	12	19
Florence	158	13	8
Frogmore Early	214	34	16
Géante de Hedelfingen ..	26	16	61
Goodneston Black	84	31	37
Governor Wood	316	80	25
Guigne d'Annonay	57	25	44
Ham Green Black ..	44	25	57
Late Black Big.	82	28	35
Mumford Black	55	8	14
Noble	141	31	22
Noir de Schmidt	97	43	44
Ohio Beauty	44	6	14
Peggy Rivers	133	58	44
Red Turk	127	92	88
Smoky Dunn	190	61	32
Stark's Gold	144	33	23
Turkey Heart	328	45	14
Ursula Rivers	224	56	25
Victoria Black	130	65	50
Waterloo	42	22	52
White Big.	127	18	14
May Duke*	170	16	9
Late Duke*	162	31	17
Morello*	75	2	3
Elton Heart.			
Selfed	*429*	*0*	*0*
Governor Wood	*113*	*0*	*0*
Bedford Prolific	475	68	14
Belle d'Orléans	58	25	43
Big. Jaboulay	71	21	29
Big. Napoleon	178	87	49
Big. Schrecken	299	107	36
Black Heart	264	69	26
Black Tartarian A ..	35	16	46
Early Purple Gean ..	49	36	75
Early Rivers	106	9	8
Emperor Francis	68	28	41
Florence	269	60	22
Frogmore Early	143	46	32
Géante de Hedelfingen ..	199	41	21
Guigne d'Annonay ..	87	29	33
Knight's Early Black ..	46	13	28
Noble	51	23	45
Peggy Rivers	23	15	65
Turkey Heart	87	32	37
Late Duke*	80	4	5
May Duke*	150	10	7
Royal Duke*	44	15	34
Wye Morello*	115	35	30
Emperor Francis.			
Selfed	*2,109*	*5*	*0*
Big. Napoleon	*1,516*	*0*	*0*
Bedford Prolific	304	100	33
Belle Agathe	189	73	39
Belle d'Orléans	62	14	23
Big. Jaboulay	50	16	32
Big. Kentish	77	9	12

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Big. Ludwig's	119	13	11
Big. Schrecken	392	115	29
Black Cluster	55	19	34
Black Eagle	369	76	21
Black Heart B	70	7	10
Black Tartarian A ..	121	29	24
Black Tartarian B ..	75	27	36
Black Tartarian E ..	31	16	52
Bohemian Black	184	52	28
Cryall's Seedling	65	2	3
Early Purple Gean ..	233	60	26
Early Rivers	205	72	35
Elton Heart	290	56	19
Florence	301	28	9
Géante de Hedelfingen ..	27	2	7
Governor Wood	173	43	25
Guigne d'Annonay	182	59	32
Knight's Early Black ..	366	53	14
Late Black Big.	200	61	30
Monstrueuse de Mezel B ..	212	53	25
Mumford Black	219	25	11
Noble	151	21	14
Noir de Guben	57	12	21
Noir de Schmidt	112	47	42
Peggy Rivers	60	9	15
Preserving	85	24	28
Roundel Heart	159	32	20
Turkey Heart	40	24	60
Ursula Rivers	37	3	8
Waterloo	218	41	19
May Duke*	28	11	39
Royal Duke*	72	12	17
Wye Morello*	39	4	10
Prunus decumana	24	13	54
Florence.			
Selfed	*188*	*0*	*0*
Bedford Prolific	33	6	18
Belle Agathe	110	43	39
Big. Jaboulay	36	23	64
Big. Kentish	66	26	39
Big. Ludwig's	32	7	22
Big. Napoleon	67	42	63
Big. Schrecken	53	11	21
Black Heart B	37	15	40
Black Tartarian D ..	25	3	12
Bohemian Black	102	28	27
Emperor Francis	129	40	31
Géante de Hedelfingen ..	99	63	64
Governor Wood	62	23	53
Monstrueuse de Mezel B ..	23	15	65
Noble	119	55	46
Noir de Schmidt	53	36	68
Peggy Rivers	46	27	59
Roundel Heart	27	12	44
Stark's Gold	45	24	53
Ursula Rivers	20	4	20

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Frogmore Early.			
Selfed	*1,201*	*0*	*0*
Belle Agathe	*281*	*0*	*0*
Big. Schrecken	*1,205*	*1*	*0*
Black Cluster	*92*	*1*	*1*
Black Elton	*256*	*1*	*0*
Black Heart B	*108*	*0*	*0*
Victoria Black	*122*	*0*	*0*
Waterloo	*406*	*1*	*0*
Baumann's May	80	36	45
Bedford Prolific	129	59	46
Beeve's Heart	28	2	7
Belle d'Orléans	78	21	27
Big. Gaucher	37	7	19
Big. Jaboulay	56	7	13
Big. Kentish	148	53	26
Big. Napoleon	258	56	22
Black Downton	175	49	28
Black Eagle	66	26	39
Black Heart	145	18	12
Black Oliver	193	47	24
Black Tartarian A ..	75	34	45
Black Tartarian B ..	73	15	20
Black Tartarian E ..	30	11	37
Bohemian Black	46	22	48
Cryall's Seedling	99	49	49
Early Purple Gean ..	12	9	75
Early Rivers	454	138	28
Elton Heart	70	10	14
Emperor Francis	362	88	24
Florence	22	11	50
Géante de Hedelfingen ..	150	56	37
Governor Wood ..	354	122	34
Guigne d'Annonay	107	21	20
Ham Green Black ..	100	39	39
Knight's Early Black ..	452	141	31
Late Black Big.	187	66	35
Monstrueuse de Mezel B ..	88	14	16
Mumford Black	88	37	42
Noble	52	20	38
Noir de Schmidt	116	29	25
Ohio Beauty	41	4	10
Peggy Rivers	131	16	12
Red Turk	85	26	31
Roundel Heart	113	56	49
Smoky Dunn	156	46	29
Stark's Gold	551	158	29
Turkey Heart	144	73	51
Ursula Rivers	26	12	47
White Big.	140	53	38
Empress Eugenie* ..	37	16	43
Late Duke*	80	0	0
May Duke*	512	72	14
Flemish Red*	166	22	13
Kentish Red*	23	11	48
Morello*	129	3	2
Wye Morello*	20	7	35

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Géante de Hedelfingen.			
Selfed	*376*	*0*	*0*
Hooker's Black	*59*	*0*	*0*
Monstrueuse de Mezel B	*214*	*0*	*0*
Baumann's May	26	6	23
Bedford Prolific	38	16	42
Beeve's Heart	42	4	9
Belle Agathe	6	4	67
Big. Dennison's	29	7	24
Big. Jaboulay	58	35	60
Big. Kentish	113	50	44
Big. Napoleon	262	40	15
Big. Schrecken	129	21	16
Black Circassian	51	11	21
Black Eagle	33	6	18
Black Elton	51	21	41
Black Heart B	85	58	68
Black Oliver	41	30	73
Black Tartarian D	45	11	24
Bohemian Black	18	12	67
Cryall's Seedling	35	4	11
Early Rivers	14	7	50
Elton Heart	110	10	9
Florence	27	9	33
Goodneston Black	52	32	61
Governor Wood	129	9	7
Guigne d'Annonay	29	9	31
Knight's Early Black	93	17	18
Late Amber	86	25	29
Leicester Black	39	3	8
Noble	181	16	9
Noir de Schmidt	177	44	25
Red Turk	93	49	53
Ronald's Heart	72	7	10
Semis de Burr	64	7	16
Smoky Dunn	95	48	50
Stark's Gold	85	18	21
Turkey Heart	65	12	18
Ursula Rivers	197	105	53
Victoria Black	40	11	27
West Midlands Big.	45	7	16
Waterloo	115	32	28
Late Duke*	40	9	22
Flemish Red*	54	9	17
Goodneston Black.			
Selfed	*38*	*0*	*0*
Late Black Big.	7	6	86
Stark's Gold	37	25	67
Governor Wood.			
Selfed	*1,711*	*3*	*0*
Elton Heart	*282*	*0*	*0*
Stark's Gold	*228*	*0*	*0*
Baumann's May	84	24	28
Bedford Prolific	95	37	39
Belle Agathe	169	49	29
Belle d'Orléans	172	65	38
Big. Jaboulay	69	20	29
Big. Kentish	145	56	39
Big. Napoleon	101	45	44
Big. Schrecken	110	31	28
Black Cluster	118	32	27
Black Eagle	115	18	16
Black Elton	76	43	56
Black Heart B	133	51	38
Black Oliver	79	18	23
Black Tartarian A	24	4	17
Black Tartarian B	123	45	36
Black Tartarian E	24	6	25
Bohemian Black	213	50	23
Early Purple Gean	58	24	41
Early Rivers	300	123	41
Emperor Francis	81	32	39
Florence	43	12	28
Frogmore Early	111	52	47
Géante de Hedelfingen	168	48	28
Goodneston Black	111	21	19
Guigne d'Annonay	45	23	51
Knight's Early Black	32	20	62
Late Black Big.	54	24	44
Monstrueuse de Mezel B	76	14	18
Noble	359	184	51
Noir de Guben	120	45	37
Noir de Schmidt	88	23	26
Peggy Rivers	69	29	42
Red Turk	33	21	64
Roundel Heart	42	30	71
Turkey Heart	123	66	54
Ursula Rivers	38	23	60
Victoria Black	37	28	76
Waterloo	45	22	49
White Big.	244	33	13
Late Duke*	33	6	18
May Duke*	12	4	33
Morello*	24	7	29
Wye Morello*	17	5	29
Guigne d'Annonay.			
Selfed	*669*	*0*	*0*
Cryall's Seedling	*74*	*0*	*0*
Big. Napoleon	174	100	57
Big. Schrecken	186	68	36
Black Oliver	37	6	16
Early Rivers	186	68	36
Emperor Francis	256	130	51
Goodneston Black	95	56	59
Governor Wood	218	90	41
Leicester Black	38	28	74
Noble	76	52	68
Noir de Schmidt	86	45	52
Stark's Gold	139	56	40
Ursula Rivers	24	13	54
May Duke*	197	74	37

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Kentish Red*	63	13	21
Morello*	105	36	34
Wye Morello*	182	132	72
HAM GREEN BLACK.			
Selfed	*10*	*0*	*0*
Big. Napoleon	15	3	20
Big. Schrecken	117	92	79
Governor Wood	45	24	53
Knight's Early Black ..	46	22	48
HOOKER'S BLACK.			
Selfed	*64*	*0*	*0*
KNIGHT'S EARLY BLACK.			
Selfed	*1,244*	*1*	*0*
Bedford Prolific	*379*	*0*	*0*
Black Eagle	*30*	*1*	*3*
Black Tartarian A ..	*120*	*0*	*0*
Black Tartarian B ..	*141*	*0*	*0*
Early Rivers	*235*	*1*	*0*
Roundel Heart	*194*	*0*	*0*
Belle Agathe	112	10	9
Big. Jaboulay	22	6	27
Big. Napoleon	161	46	28
Big. Schrecken	100	27	27
Black Elton	38	22	58
Black Tartarian E ..	44	12	27
Cryall's Seedling	17	6	35
Frogmore Early	99	20	20
Goodneston Black 6 ..	12	2	17
Governor Wood	99	19	19
Guigne d'Annonay	87	28	32
Noir de Guben	47	24	51
May Duke*	116	0	0
Kentish Red*	23	3	13
Morello*	25	9	36
Wye Morello*	15	1	7
LARGE BLACK.			
Selfed	*40*	*0*	*0*
LATE AMBER.			
Selfed	*82*	*0*	*0*
LATE BLACK BIGARREAU.			
Selfed	*1,274*	*2*	*0*
Bohemian Black	*517*	*1*	*0*
Turkey Heart	*321*	*1*	*0*
Bedford Prolific	79	29	37
Belle d'Orléans	18	5	28
Big. Gaucher	87	29	33
Big. Kentish	250	109	44
Big. Ludwigs	174	67	38
Big. Napoleon	106	27	25
Big. Schrecken	317	142	45
Black Downton	102	30	29

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Black Elton	58	13	22
Black Oliver	139	28	20
Early Purple Gean ..	281	60	21
Early Rivers	376	125	33
Emperor Francis	127	31	24
Florence	84	26	31
Frogmore Early	8	4	50
Goodneston Black	61	14	23
Governor Wood	193	61	32
Knight's Early Black ..	30	12	40
Mumford Black	156	11	7
Noir de Guben	221	37	17
Noir de Schmidt	384	100	26
Preserving	40	16	40
Red Turk	94	40	42
Roundel Heart	143	38	27
Smoky Dunn	85	29	34
Victoria Black	59	12	20
Waterloo	21	5	24
White Big.	105	21	20
Empress Eugenie* ..	75	21	28
May Duke*	65	24	37
Wye Morello*	83	30	36
LEICESTER BLACK.			
Selfed	*199*	*0*	*0*
MONSTRUEUSE DE MEZEL B.			
Selfed	*363*	*0*	*0*
Géante de Hedelfingen ..	*206*	*0*	*0*
Bedford Prolific	61	13	21
Belle Agathe	84	14	17
Belle d'Orléans	50	10	20
Big. Kentish	110	28	25
Big. Ludwigs	9	1	11
Big. Napoleon	187	58	31
Big. Schrecken	34	12	35
Black Cluster	40	8	20
Black Eagle	94	9	10
Black Elton	40	14	35
Black Heart B	79	41	52
Black Tartarian D ..	153	62	40
Bohemian Black	99	45	45
Elton Heart	17	11	65
Emperor Francis	25	4	16
Florence	57	32	56
Frogmore Early	21	12	57
Governor Wood	32	2	6
Guigne d'Annonay ..	57	29	51
Ham Green Black ..	37	16	43
Noir de Schmidt	12	6	50
Peggy Rivers	11	4	36
Stark's Gold	69	36	52
Ursula Rivers	165	46	28
Victoria Black	50	27	54
White Big.	53	10	19
Morello*	35	12	34

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Mumford Black.			
Selfed	45	0	0
Big. Ludwigs	19	3	16
Big. Schrecken	27	3	11
Cryall's Seedling	39	10	26
Guigne d'Annonay	30	12	40
Noir de Schmidt	40	3	7
Peggy Rivers	64	7	11
Stark's Gold	51	10	20
Noble.			
Selfed	1,275	5	0
Bedford Prolific	150	41	27
Belle Agathe	30	7	23
Big. Jaboulay	114	40	35
Big. Kentish	50	12	24
Big. Napoleon	483	172	36
Big. Schrecken	155	37	24
Black Cluster	21	3	14
Black Eagle	115	14	12
Black Heart	22	10	45
Black Tartarian B	25	5	20
Bohemian Black	57	21	37
Cryall's Seedling	41	22	54
Early Rivers	51	20	39
Elton Heart	203	55	27
Emperor Francis	93	14	15
Florence	192	72	37
Frogmore Early	201	73	36
Géante de Hedelfingen	96	18	19
Governor Wood	61	10	16
Guigne d'Annonay	40	13	32
Knight's Early Black	70	35	50
Monstrueuse de Mezel B	211	50	24
Noir de Guben	133	35	26
Noir de Schmidt	101	37	37
Stark's Gold	51	20	39
Turkey Heart	19	12	63
Ursula Rivers	218	75	34
Waterloo	118	38	32
White Big.	495	81	16
Late Duke*	76	17	22
Flemish Red*	123	18	15
Kentish Red*	72	4	5
Wye Morello*	26	2	8
Noir de Guben.			
Selfed	1,425	2	0
Belle Agathe	122	51	42
Belle d'Orléans	161	74	46
Big. Jaboulay	78	33	42
Big. Napoleon	88	26	29
Big. Schrecken	330	24	7
Black Tartarian E	71	33	46
Bohemian Black	288	108	37
Early Purple Gean	193	108	56
Early Rivers	160	98	61
Frogmore Early	36	26	72
Géante de Hedelfingen	106	46	43
Governor Wood	62	31	50
Guigne d'Annonay	200	116	58
Ham Green Black	64	33	51
Noir de Schmidt	98	47	48
Roundel Heart	92	34	37
Stark's Gold	59	37	63
May Duke*	67	6	9
Kentish Red*	99	46	46
Morello*	63	21	33
Noir de Schmidt.			
Selfed	1,617	2	0
Peggy Rivers	209	0	0
Bedford Prolific	67	4	6
Belle d'Orléans	156	27	17
Big. Gaucher	92	29	31
Big. Jaboulay	56	6	11
Big. Kentish	149	28	19
Big. Ludwigs	73	25	34
Big. Napoleon	174	37	21
Big. Schrecken	100	12	12
Black Cluster	42	2	5
Black Eagle	88	12	14
Black Heart B	85	18	21
Black Tartarian A	83	2	2
Bohemian Black	234	27	11
Cryall's Seedling	61	30	49
Early Purple Gean	42	9	21
Early Rivers	113	11	10
Elton Heart	87	4	5
Emperor Francis	70	10	14
Florence	141	21	15
Frogmore Early	48	22	46
Géante de Hedelfingen	17	3	18
Goodneston Black	62	11	18
Governor Wood	31	7	23
Guigne d'Annonay	141	50	35
Knight's Early Black	201	47	23
Late Black Big.	615	117	19
Large Black	55	15	27
Monstrueuse de Mezel B	62	16	26
Mumford Black	114	38	33
Noble	550	67	12
Noir de Guben	93	19	20
Preserving	30	4	13
Ronald's Heart	112	9	8
Stark's Gold	197	17	9
Ursula Rivers	36	13	36
Waterloo	19	3	16
White Big.	85	8	9
Late Duke*	111	14	13
May Duke*	43	11	25
Royal Duke*	44	10	23
Reine Hortense*	46	9	19
Wye Morello*	31	11	35
Prunus decumana	33	4	12

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Ohio Beauty.			
Selfed	*15*	*0*	*0*
Big. Napoleon	*24*	*0*	*0*
Bedford Prolific	104	7	7
Peggy Rivers.			
Selfed	*60*	*0*	*0*
Noir de Schmidt	*30*	*0*	*0*
Baumann's May	42	13	31
Big. Kentish	65	25	38
Big. Napoleon	67	22	33
Big. Schrecken	22	4	18
Black Downton	27	13	48
Black Elton	28	11	39
Black Oliver	58	12	21
Black Tartarian D	242	73	31
Bohemian Black	37	5	13
Early Purple Gean	32	6	19
Early Rivers	39	10	26
Goodneston Black	93	61	65
Governor Wood	96	24	25
Knight's Early Black	24	13	54
Red Turk	78	27	35
Preserving.			
Selfed	*42*	*0*	*0*
Bedford Prolific	23	7	30
Big. Napoleon	50	44	88
Knight's Early Black	41	31	76
Red Turk.			
Selfed	*61*	*0*	*0*
Ursula Rivers	*198*	*1*	*0*
Black Downton	93	40	43
Black Elton	18	16	89
Governor Wood	89	19	21
Turkey Heart	25	9	36
Ronald's Heart.			
Selfed	*103*	*0*	*0*
Roundel Heart.			
Selfed	*52*	*0*	*0*
Bedford Prolific	*94*	*0*	*0*
Black Eagle	*170*	*0*	*0*
Early Rivers	*33*	*0*	*0*
Knight's Early Black	*67*	*0*	*0*
Belle Agathe	36	8	22
Big. Ludwigs	33	3	9
Big. Napoleon	50	21	42
Big. Schrecken	46	9	20
Emperor Francis	92	12	13
Governor Wood	31	27	87
Late Black Big.	71	22	31
Noble	31	22	71
Waterloo	54	26	48

* Indicates tetraploid varieties.

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Semis de Burr.			
Selfed	*56*	*0*	*0*
Big. Schrecken	*18*	*0*	*0*
Big. Napoleon	42	7	17
Early Rivers	37	4	11
Smoky Dunn.			
Selfed	*131*	*0*	*0*
Early Rivers	121	31	26
Governor Wood	11	1	9
Red Turk	29	13	45
Stark's Gold.			
Selfed	*83*	*0*	*0*
Governor Wood	*188*	*0*	*0*
Bedford Prolific	60	5	8
Big. Dennisons	26	17	65
Big. Napoleon	50	27	54
Big. Schrecken	50	9	18
Black Circassian	150	13	9
Black Downton	137	26	19
Black Elton	58	20	34
Black Oliver	75	11	15
Early Rivers	23	15	65
Frogmore Early	27	18	67
Géante de Hedelfingen	91	29	32
Goodneston Black	91	12	13
Noble	170	27	16
Noir de Schmidt	130	40	31
Red Turk	112	25	22
Smoky Dunn	48	8	17
Turkey Heart	91	5	5
Ursula Rivers	47	5	11
Victoria Black	93	15	16
Waterloo	119	50	42
Turkey Heart.			
Selfed	*1,319*	*3*	*0*
Bohemian Black	*418*	*1*	*0*
Late Black Big.	*198*	*1*	*0*
Bedford Prolific	106	17	16
Belle Agathe	186	20	11
Big. Gaucher	66	8	12
Big. Kentish	172	95	55
Big. Ludwigs	178	36	20
Big. Napoleon	191	31	19
Big. Schrecken	177	6	3
Black Circassian	38	3	8
Black Eagle	51	8	16
Black Heart B	89	34	38
Early Rivers	91	8	9
Emperor Francis	130	29	22
Florence	24	7	29
Frogmore Early	172	27	16
Géante de Hedelfingen	125	16	13
Governor Wood	95	28	29

Pollinations.	Flowers pollinated.	Fruits matured.	Per cent. matured.
Guigne d'Annonay	151	34	22
Hooker's Black	38	3	8
Knight's Early Black	182	69	38
Monstrueuse de Mezel B	232	18	8
Noble	73	18	25
Noir de Schmidt	71	6	8
Ohio Beauty	84	32	38
Roundel Heart	259	15	6
Semis de Burr	65	15	3
Ursula Rivers	36	14	39
Waterloo	202	43	21
White Big.	69	14	20
Yellow Spanish	34	4	12
Ursula Rivers.			
Selfed	*173*	*0*	*0*
Red Turk	*93*	*0*	*0*
Big. Kentish	111	13	12
Big. Napoleon	88	21	24
Black Elton	60	3	5
Black Oliver	62	15	24
Black Tartarian D	169	27	16
Early Rivers	33	5	15
Frogmore Early	106	10	9
Géante de Hedelfingen	108	57	53
Goodneston Black	34	5	15
Governor Wood	40	9	22
Guigne d'Annonay	102	12	12
Noble	181	55	30
Peggy Rivers	19	6	32
Smoky Dunn	29	2	7
Stark's Gold	173	37	21
Victoria Black	52	7	13
Waterloo	142	20	14
Victoria Black.			
Selfed	*385*	*0*	*0*
Big. Schrecken	*60*	*0*	*0*
Black Elton	*24*	*0*	*0*
Frogmore Early	*63*	*0*	*0*
Big. Gaucher	15	1	7
Big. Kentish	150	16	11
Big. Napoleon	19	2	10
Black Downton	58	16	27
Géante de Hedelfingen	96	7	7
Governor Wood	60	5	8
Knight's Early Black	100	22	22
Red Turk	10	3	30
Waterloo.			
Selfed	*1,086*	*0*	*0*
Belle Agathe	*89*	*0*	*0*
Big. Schrecken	*93*	*0*	*0*
Black Cluster	*65*	*0*	*0*
Black Heart B	*24*	*0*	*0*
Frogmore Early	*113*	*0*	*0*
Bedford Prolific	204	33	16
Big. Kentish	215	80	37
Big. Napoleon	81	8	10
Black Tartarian A	29	10	34
Black Tartarian B	215	22	10
Black Tartarian D	36	4	11
Early Rivers	94	12	13
Emperor Francis	145	19	13
Florence	78	26	33
Géante de Hedelfingen	72	35	49
Knight's Early Black	70	6	8
Noble	277	67	24
Noir de Schmidt	75	4	5
Roundel Heart	117	15	13
Ursula Rivers	213	30	14
May Duke*	312	69	22
Morello*	199	94	47
West Midlands Bigarreau.			
Selfed	*28*	*0*	*0*
White Bigarreau.			
Selfed	*231*	*0*	*0*
Big. Kentish	*422*	*0*	*0*
Big. Ludwigs	*85*	*0*	*0*
Belle Agathe	86	7	8
Big. Jaboulay	96	10	10
Big. Napoleon	329	39	12
Frogmore Early	106	20	19
Prunus decumana	27	3	11
White Heart.			
Big. Schrecken	50	14	28
Early Rivers	205	72	35
May Duke*	200	30	15
Kentish Red*	200	22	11
Yellow Spanish.			
Selfed	*25*	*0*	*0*
Early Rivers	31	4	13

* Indicates tetraploid varieties.

(*Received* 10/3/37.)

FIG. 1.

Bigarreau Noir de Guben. Right hand side and centre, pollinated with Knight's Early Black. Left hand side self-pollinated. 20 days after pollination.

FIG. 2.

Black Tartarian " A " (Group I), showing incompatible pollinations = flowers pollinated 715, fruits set 0. Compatible pollinations = flowers pollinated 717, fruits set 74. Average set of fruit from compatible pollinations = 10·3 per cent.

FIG. 3.

Bigarreau Napoleon (Group III), showing incompatible pollinations=flowers pollinated 521, fruits set 0. Compatible pollinations=flowers pollinated 327, fruits set 183. Average set of fruit from compatible pollinations=55·9 per cent.

Fig. 4.
Normal and Albino Seedlings, from Ursula Rivers crossed Géante de Hedelfingen.

CITRUS MANURING—ITS EFFECT ON CROPPING AND ON THE COMPOSITION AND KEEPING QUALITY OF ORANGES

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THE primary object of the work reported on here was to determine the interaction of the most common artificial fertilizers used in citrus orchards and the influence of such fertilizers on the composition and quality of oranges and on their keeping quality. Preliminary to this, much information was acquired concerning the effect on cropping and on general growth, and as such data should also be interpreted in the light of the later results on composition and quality, it is felt that these results should be presented as the first part of this paper.

TREATMENTS.

An orchard of approximately 2,500 Washington Navel orange trees was selected for this purpose. The trees were all on rough lemon stock and were eight years old in the orchard at the time of applying differential treatments in 1931. The orchard was planted on the quincunx system at the rate of approximately 100 trees per acre, so that it was convenient for the plots to consist of five trees each ; three buffer rows were left between each two plots. Each of the twenty treatments was replicated six times and the plots were laid out by the randomized block method.

The treatments employed were as follows:—

1. Control.
2. $K_3P_3N_3$.
3. $K_2P_3N_3$.
4. KP_3N_3.
5. P_3N_3.
6. K_3.
7. $K_3P_2N_3$.
8. K_3PN_3.
9. K_3N_3.
10. P_3.
11. $K_3P_3N_2$.
12. K_3P_3N.
13. K_3P_3.
14. N_3.
15. $K_3P_3N_2$ (Nitrogen applied in two equal amounts, one in early spring, before blossoming, and the other just after fruit set, i.e. about six to eight weeks later).
16. $K_3P_3N_3$ (Lime applied at rate of 20 lb. per tree).
17. $K_3P_3N_3$ (Clean cultivation—no weeds or cover crops).
18. K_3P_3 (Leguminous cover crops sown at rate of 10 lb. *Crotalaria juncea* + 10 lb. Iron Cowpeas per acre).
19. K_3P_3N (Leguminous cover crop as for treatment 18).
20. $K_3P_3N_2$ (ditto.).

The symbols used above are to be interpreted as follows:—

K = 1 lb. K_2SO_4 per tree.	P = 2 lb. superphosphate per tree.
K_2 = 2 ,, ,, ,, ,,	P_2 = 4 ,, ,, ,, ,,
K_3 = 3 ,, ,, ,, ,,	P_3 = 6 ,, ,, ,, ,,
N = 2 lb. $(NH_4)_2SO_4$ per tree.	
N_2 = 4 ,, ,, ,, ,,	
N_3 = 6 ,, ,, ,, ,,	

The fertilizers were broadcast evenly over the whole area allotted to each tree in the orchard in very early spring about a month before blossoming. Approximately four inch irrigations were applied by the basin system immediately after the application of the fertilizers and as nearly as practicable every six weeks thereafter, unless rain replaced irrigation. The lime applied in treatment 16 was thoroughly forked in before irrigation.

SOIL TYPE.

The soil is of mixed origin, mostly colluvial, overlying residual soils. According to mechanical analysis it belongs to the sandy clays, but on account of its well-flocculated condition it behaves more like a loam. Its physical condition ensures good drainage.

The pH varies at different depths and in different plots from 5·5 to 6·5.

In Table I a composite chemical analysis (excluding nitrogen) is given illustrating the general composition of the soil prior to differential treatment.

TABLE I.*

Depth of sample.	Specific resistance at 60°C. ohms.	HCl (S.G. 1·113) Extract.							1% Citric acid extract.	
		CaO	MgO	K_2O	P_2O_5	Fe_2O_3	Al_2O_3	Insoluble Residue.	K_2O	P_2O_5
		%	%	%	%	%	%	%	%	%
0-12 ins. ..	1100	·86	·35	·32	·055	3·35	4·55	87·0	·017	·006
12-24 ins. ..	1250	·68	·34	·32	·051	3·73	5·18	85·7	·017	·005
24-36 ins. ..	1000	·72	·34	·36	·048	4·48	6·60	82·9	·014	·003
36-48 ins. ..	800	·74	·39	·38	·043	4·57	6·71	82·0	·014	·002

* From Kamerman, P. and Klintworth, H. S. Afr. Dept. Agr. Sci. Bull. 137, 1934.

According to the above Table the soil can be assumed to be well supplied with mineral plant nutrients, especially with " available " K_2O and P_2O_5.

RECORDING AND SAMPLING.

Crop. The fruit from each tree in every plot was harvested, counted and weighed separately. The weighing was conveniently expedited by using a good spring balance suspended from a cross bar resting on the shoulders of two labourers. Attached to the hook of the balance was a large specially constructed pair of tongs which worked on the principle of ice tongs. The two labourers with the weighing arrangement between them walked one on each side of a row of boxes filled with fruit, and by means of the tongs lifted one box after the other ; the recorder read and wrote down the weight of each box.

The trees were stripped of out-season fruit simultaneously with harvesting the ordinary crop, and the number and weight of out-season fruits was recorded separately.

Growth of trees. It has been shown by various investigators (11, 10, 19, 40) that either the cross-sectional area or the circumference of the trunk is a satisfactory index of the size of the tree. The effect of fertilizers on growth of tree was accordingly recorded by measuring the circumference of the trunk of each tree at the time when the treatments were first applied and again at yearly intervals for the five years of the investigation. The position of the first measurement was retained by marking the trunk with a ring of white paint.

Fruit rind thickness. When the fruits were being cut in half prior to extracting the juice, the thickness of the rind of each orange was measured at one point on the cut surface. This figure was taken as comparative for the rind thickness of oranges from all the plots.

Keeping quality. For all records concerning fruit, one size was used throughout. It was arbitrarily decided to use fruit with an average diameter of $3\frac{1}{8}$ inches, thus packing 126 in the standard Citrus box. The fruit from the five trees in each plot was grouped together and passed over a small grader in order to segregate all the fruits of $3\frac{1}{8}$ inch diameter. The fruits of this size having been thoroughly mixed, a random sample of 126 oranges was wrapped and packed into a box for storage purposes. In this way there were six boxes, each representing one of the six replicates of each treatment, a total of 120 boxes. The boxes of oranges were despatched by rail a distance of approximately 200 miles to the nearest commercial cold store where they were kept for three weeks at a temperature ranging from 38° F. to 42° F. After cold storage the boxes were kept at atmospheric temperature ranging from 35° F. to 65° F. for a period of one to two months, when all the fruits were unwrapped and examined for wastage.

No attempt was made to segregate types of wastage caused by different fungi, and fruits showing superficial skin blemishes which might have developed in cold storage were not classified as wastage.

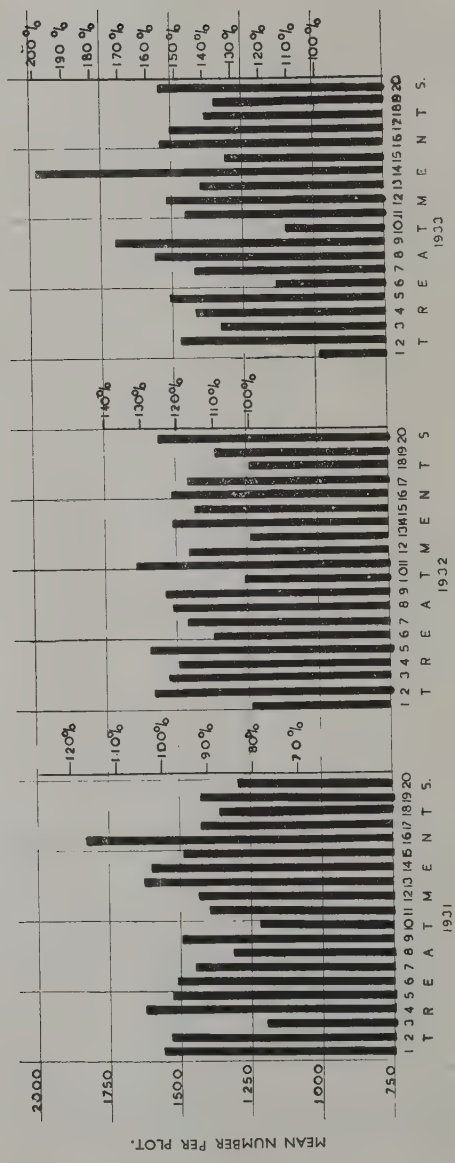


Diagram I.
In-Season Crops expressed as number of fruits.

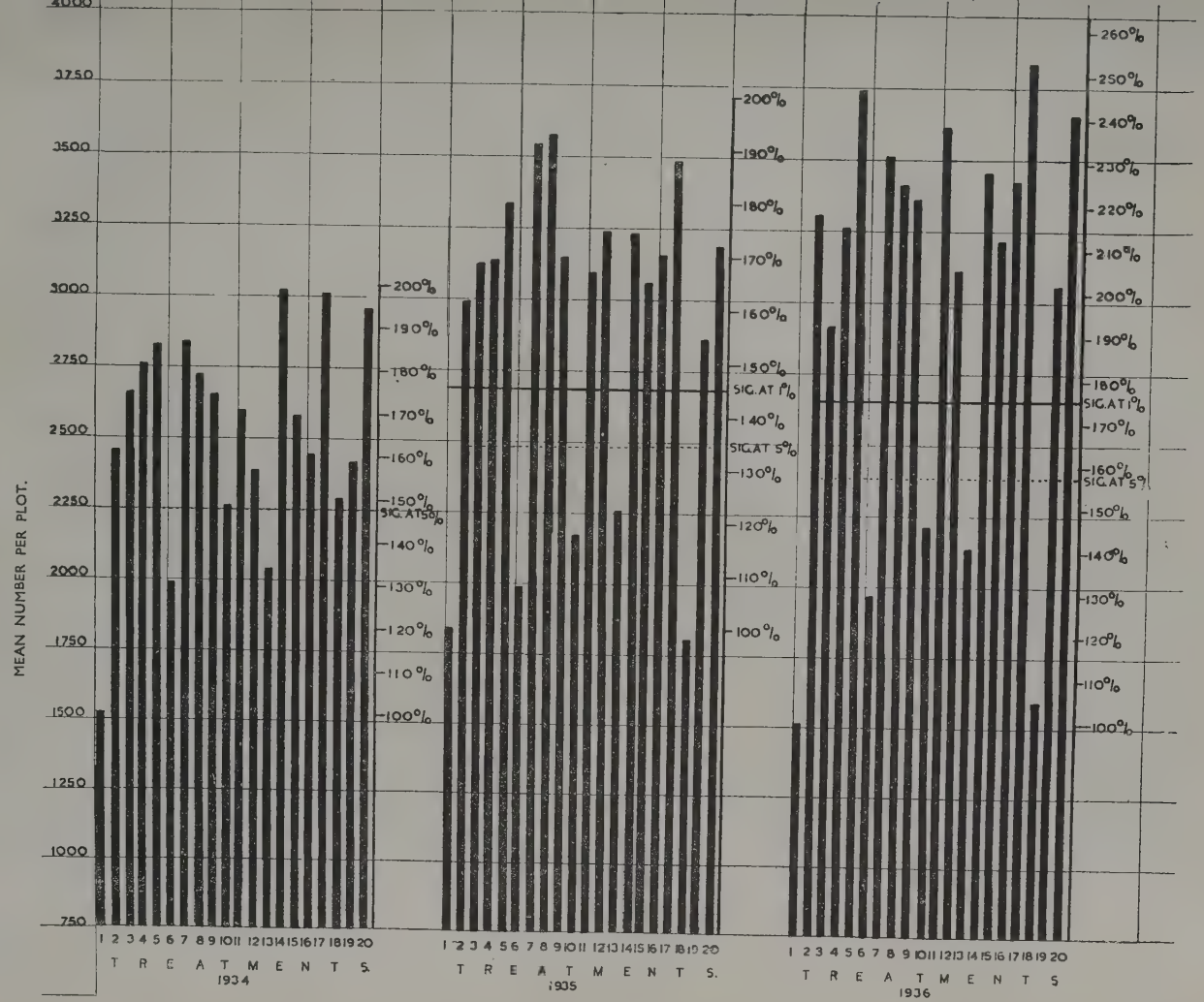


Diagram II.
In-Season Crops expressed as number of fruits.

Chemical analysis. Six fruits, each of a diameter of $3\frac{1}{8}$ inches, were taken at random from each tree to make a composite sample of thirty fruits representing each plot. There were thus six separate samples to be analysed for each of the twenty treatments. The juice from each sample of thirty fruits was extracted by means of an electric reamer and after thorough mixing aliquot parts were taken for the various analyses. Samples of rind and pulp were taken just prior to extracting the juice from the same groups of fruit. The analyses of these will be reported upon later.

Juice content. Representative samples of pulp were procured by cutting a thin cross slice from each orange after it had been halved prior to squeezing. The thirty slices from each sample formed a composite sample.

Meteorological records. A complete meteorological station was established and records taken throughout the period of this investigation.

ANALYTICAL METHODS.

Total soluble solids: By the use of a refractometer graduated to read as percentage sugar.

Acid: Titration with KOH.

Sugar: Picric acid colorimetric method (41).

Juice: The percentage moisture in the pulp was found by drying at 75° C. for forty-eight hours and expressing the difference in weight on the dry basis.

Ash: The percentage ash referred to herein signifies sulphate ash, obtained by igniting with sulphuric acid.

Dry weight of juice: Dried in oven for twenty-four hours at 75° C.

Ca: As calcium oxalate, titrated against $KMnO_4$.

K: As potassium cobalti-nitrite, by Hibbard's method (21).

P: As phosphate, by the molybdate colorimetric method.

N: Kjeldahl method.

STATISTICAL ANALYSIS OF DATA.

All the data collected during this investigation were subjected to statistical analysis according to the methods recommended by Fisher (13), before any conclusions were drawn. Fisher's Analysis of Variance, "t" test and correlation and regression coefficient calculations having been applied throughout, it merely remains, when presenting the results in the following paragraphs, to indicate whether the results, if significant, are so at the 5% (represented in the Tables, *) or 1% point (represented, **).

RESULTS AND CONCLUSIONS.

Number of fruits. Diagrams I and II represent the effect of treatment on the number of the in-season crop. The mean number of fruits per plot per treatment is determined by reference to the figures on the left of the diagrams. The figures alongside the vertical line on the right of each diagram express the mean for each treatment as a percentage of the control (treatment 1), and the control is thus always indicated as 100%. Furthermore, "significance lines" are shown running across the diagrams which show at a glance when increases or decreases in crop over control are significant at the 5% point or at the 1% point. It will be noted that most of the plots yielded a crop less than the control plots during the pre-treatment year, namely 1931. Although the variability in yield was so great that no significant difference in number of fruits due to treatment can be proved during the first two years after treatment—1932 and 1933—it is very striking that during both those years, nearly all treatments induced crops greater than that of the control. Furthermore, these increases over the control were progressive from year to year.

It is only in 1934, 1935 and 1936 that it is possible to prove statistically an increase in the number of fruits. The upper solid horizontal line cutting the vertical bars represents significance at the 1% point and the lower broken line significance at the 5% point. It should be made clear that the distance from a significance line to the top of the bar representing the control, can be used also as a criterion of significance between any other two treatments.

The outstanding results of these treatments is the marked effect of applications of nitrogen in increasing the number of fruits. All plots receiving nitrogen —irrespective of amount—yielded a significantly increased crop, whereas treatments 6, 10 and 13 (K_3, P_3 and K_3P_3) induced crops which may be considered within the range of the experimental error from the control plots.

Furthermore, there is no demonstrable difference resulting from the various quantities of nitrogen applied, so that it may be assumed that as far as number of fruits is concerned in this orchard, no particular benefit can be expected from applying more than 2 lb. of ammonium sulphate per tree.

The application of nitrogen in two doses (treatment 15) has not been reflected in an increased crop over treatment 11 when the same total amount of nitrogen was applied at one time, nor has the application of lime resulted in an increased crop. Clean cultivation (treatment 17) also shows no change in number of fruits over treatment 2 where a volunteer weed cover crop was allowed to grow ; the duration of the investigation presumably did not allow any possible effect to manifest itself, although the lack of application of organic matter has been known to manifest itself in three years (31).

The last three treatments, which include an annual leguminous cover crop, again raise the contentious question as to whether a leguminous cover crop

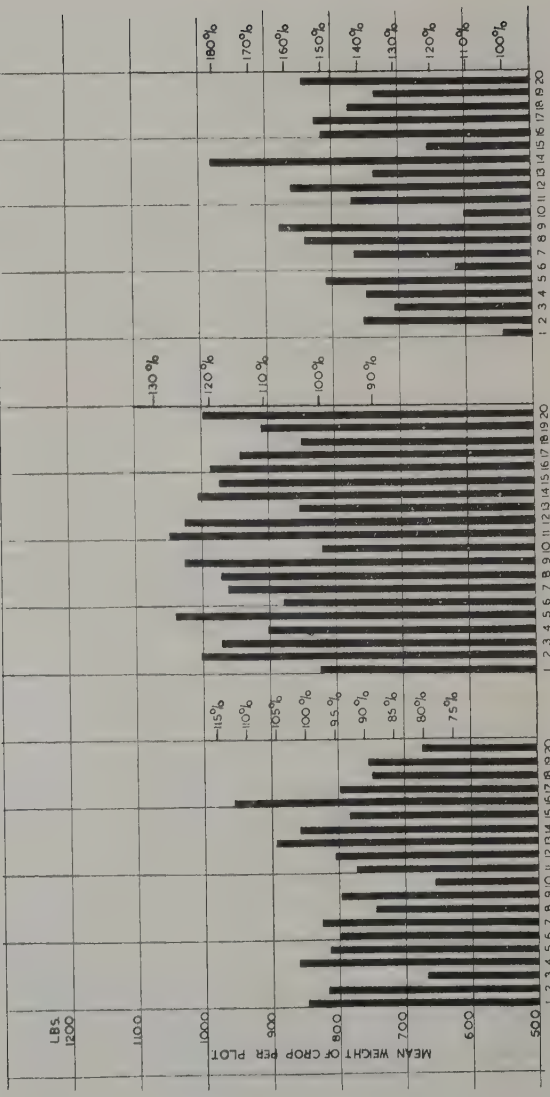


Diagram III.

In-Season Crops, expressed as weight of fruits.

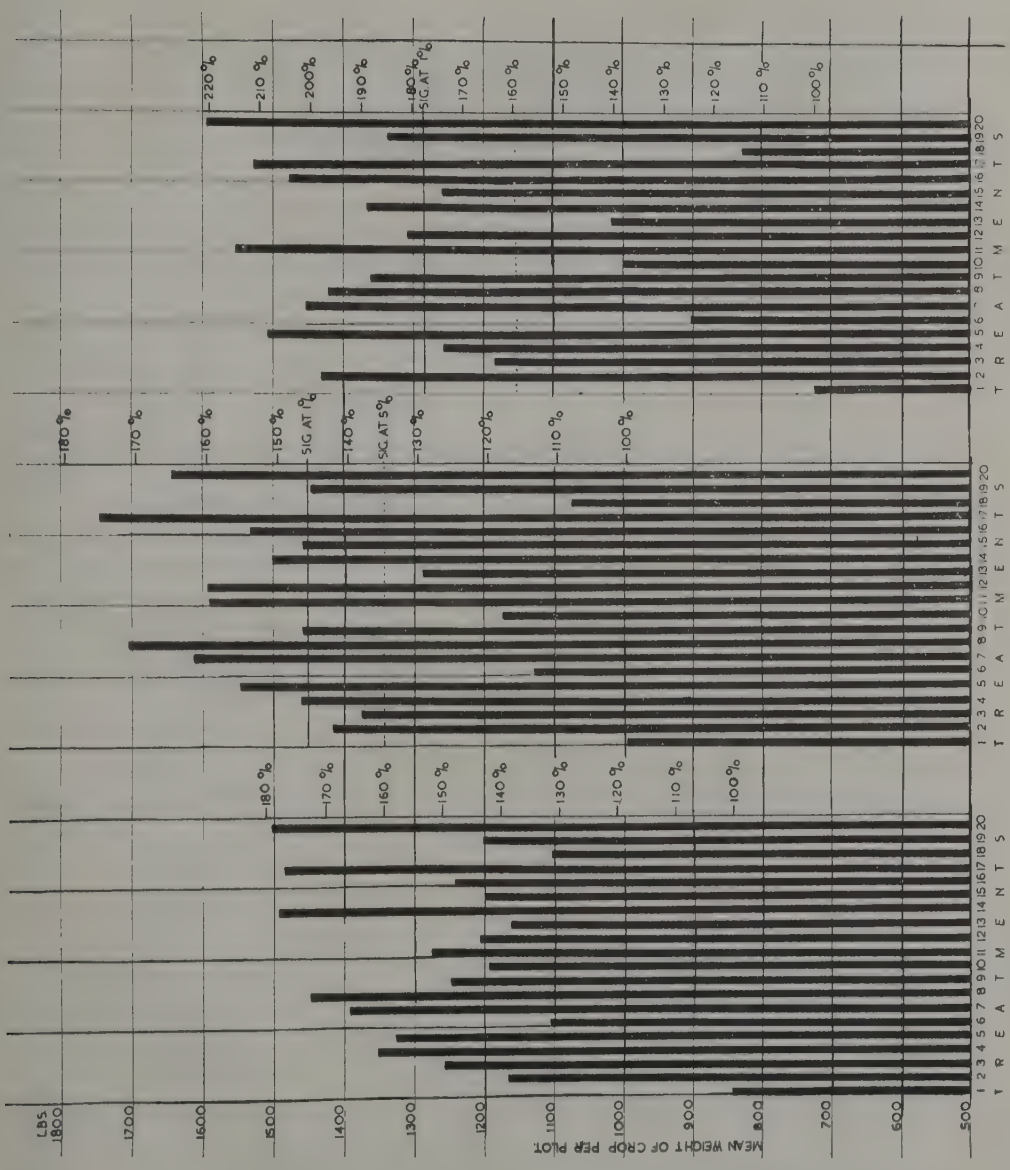


Diagram IV.

In-Season Crops, expressed as weight of fruits.

always increases the nitrogen content of the soil. Treatment 18, in which a leguminous cover crop was grown but no nitrogen was added as a fertilizer, returned very poor crops indeed, showing no demonstrable increase or decrease over the control. The significant increase in number of fruits from treatments 19 and 20 over treatment 18 may be attributed to the nitrogen added as fertilizer and not to the leguminous cover crop. At any rate there is no significant difference between the crops from treatments 20 and 11 which are identical except that in the former a leguminous cover crop was grown.

There appears to be no consistent increase from year to year in the number of fruits from the control plots. Although measurements have shown a definite increase in the size of trees from all plots, including the controls, the control trees have not produced a progressively larger crop. It is assumed, therefore, that nitrogen is the limiting factor in this orchard, so that although the trees became larger every year, the limited nitrogen supply induced approximately the same crop. The generally small crops in 1932 and 1933 can be put down to the fact that the trees suffered to a certain extent from drought conditions during those years, when irrigation water supplies were depleted.

The very significant increase during 1935 and 1936 in numbers of fruits in plots where nitrogen was applied cannot be ascribed to a greater increase in size of these trees than in the controls, for it will be shown later that trees receiving nitrogen had not increased in size over trees in the control plots.

Weight of crop. Diagrams III and IV illustrate the results for the weight of crop in the same manner as I and II present the data for the number of fruits. It will be noted that these diagrams follow very closely those for number of fruits, so that the same conclusions hold for both. There is merely one important difference, namely, that no significant increase in weight due to nitrogen treatment can be proved statistically for 1934, whereas the number of fruits in 1934 was increased significantly at the 5% point by nitrogen treatment.

Size of fruits. Actual sizes of fruits were not recorded during this investigation, but an estimate of size was determined by adjusting (by the analysis of co-variance) weight for number, two factors which showed a very high positive correlation annually. The analysis of co-variance did not, however, show any significant effect due to treatment, so that it can be concluded that size (i.e. weight per orange) is approximately the same for all treatments. This, then, confirms the conclusion to be drawn from the close similarity between the diagrams, namely that any increase in weight of crop is due to an increase in number of fruits and not to an increase in size of the fruits.

Out-season fruits. The numbers of out-season fruits harvested are represented in diagrams V and VI in the same manner as the data for in-season fruits. In order to save space in reproduction, the weights of out-season fruits

are not shown here, but such diagrams closely follow V and VI, in the same way that I and II and III and IV follow much the same tendencies.

As indicated above, the number and weight of out-season fruits were recorded in the same manner as for the normal seasonal fruits. The main object of this was to keep a record of all the fruit borne by each tree and thus to have an approximate estimate of the drain on the nutritional supplies of the tree. It is popularly contended by growers that a tree bearing a heavy out season crop will bear a poor in-season crop the following year. From a nutritional point of view this seems a reasonable assumption provided that nutrition is a limiting factor: and it was one of the objects of this investigation to acquire some information on this point and on the influence of fertilizers on the size of the out-season crop.

On determining an analysis of variance for number of out season fruits, it was found that during no year was the number of out-season fruits significantly affected by treatment.

Any possible differential effect of fertilizers on number of out-season fruits was completely masked by apparently more important factors, such as moisture and temperature relationships.

As treatment did not appear to affect the number of out season fruits it was decided to determine whether the number of in-season fruits was correlated with that of out-season fruits during any one year. The calculation of correlation coefficients showed a very strong negative correlation, significant at 1%, during 1031, 1032, 1033 and 1034: during 1035 there was also a negative correlation but not a significant one, and in 1030 a negative correlation significant at 5%. This is what might be expected from a nutritional point of view when account is taken of the tremendous drain on the nitrogen supply of the tree occasioned by blossoming and setting of the fruit (7) and by allowing the fruit to hang on the tree (8). When a large crop of in-season fruit sets during spring, the nitrogen and possibly other nutrient supplies of the tree are so depleted that any blossoming which may take place during the following summer would not cause much fruit to be set: thus, it is found that a large in-season crop is correlated with a small out-season crop and vice versa. The fact that this negative correlation was not as significant during 1035 and 1030 as during the first three years, is explained by the accumulation of nitrogen that took place during the first three years of the investigation, due to treatment.

The next test applied to the data was to determine whether a large out-season crop in one year would cause a small in-season crop during the following year. With the exception of the 1032 out-season and the 1033 in-season crop, none of these calculations for the five years of the investigation showed any significant correlations whatsoever. The negative correlation, significant at 1%, between the 1032 out-season and the 1033 in-season crop might possibly

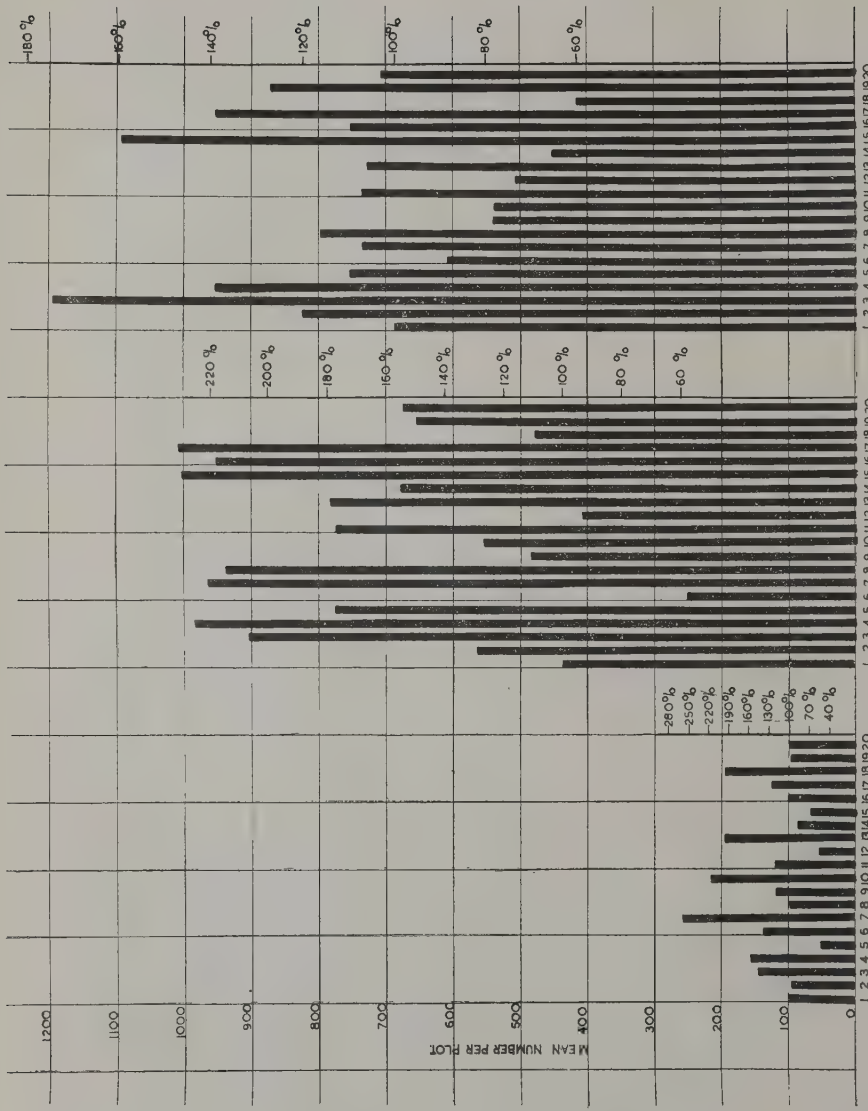


Diagram V.

Out-Season Crops, expressed as number of fruits,

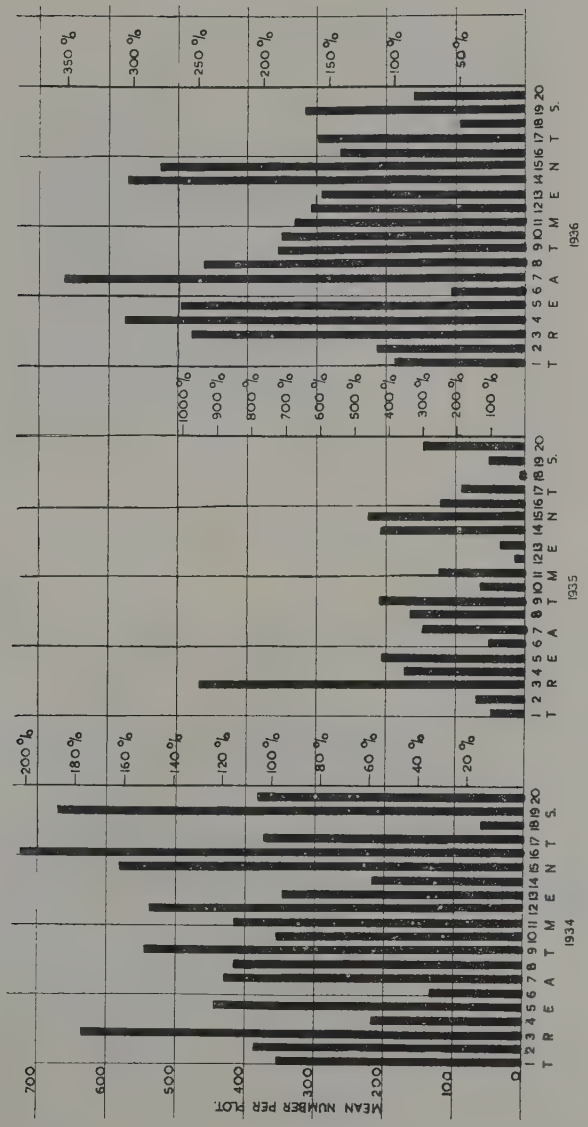


Diagram VI.

Out-Season Crops, expressed as number of fruits.

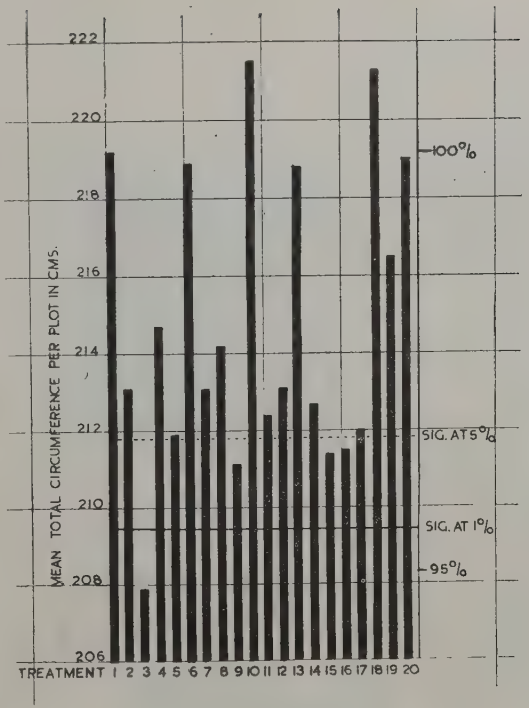


Diagram VII.

Circumference of trunks (1936) after adjustment for pre-experimental measurements.

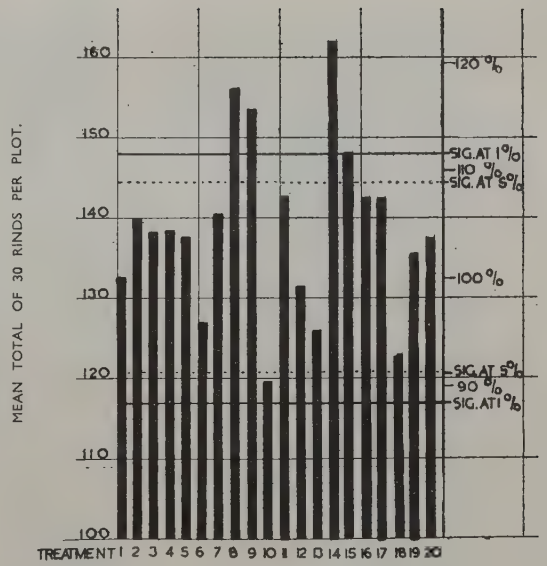


Diagram VIII.

Thickness of rind (1936), in mm.

be explained by the fact, shown in diagrams V and VI, that during 1932 there was a heavy out-season crop ; this may have been brought about by irregular moisture conditions during this year, when the country experienced a very severe drought, or by the fact that the trees were low in nitrogen at the start of these investigations and had not yet accumulated sufficient nitrogen from the first application of fertilizers to set a heavy in-season crop (diagram I, 1932), but could, during the following summer, set a heavy out-season crop.

This nearly general lack of correlation means that as the out-season fruit was harvested simultaneously with the in-season fruit (early winter) the trees had sufficient time to build up enough reserves of food materials before spring and blossoming time to set a good crop of in-season fruit, irrespective of the size of the previous out-season crop. Had the out-season fruit, however, been allowed to mature on the tree, then it is probable that the trees would have been unable to set a good crop of in-season fruit during the following spring ; in such a case there would most probably be a significant negative correlation between one year's out-season crop and the following year's in-season crop. This assumes, however, that only enough nutrient materials are available to the tree to bear one crop per year ; it is conceivable, on the other hand, that the constant availability of large quantities of food materials may make it possible for a tree to mature a considerable out-season crop as well as a good in-season crop.

In order to determine whether the procedure of pulling off the green out-season fruit during the harvesting period of the in-season fruit had any effect on the "habit" of trees to bear out-season fruit, correlations were calculated between the number of out-season fruits from year to year. A positive correlation, significant at 1%, was found between the numbers of out-season fruits for 1931-2, 1932-3, 1935-6 and 1931-6, but no significant correlation between those of 1933-4 and 1934-5. It would be legitimate to conclude from this that, contrary to the commonly expressed opinion of growers, the stripping of trees of out-season crops at the time of harvesting the normal crop does not influence the so-called " habit " of trees to bear out-season fruit. As has been suggested above, however, this stripping of the trees of out-season fruit may affect the following in-season crop favourably if the trees have not a considerable nutritional reserve.

Growth of trees. The appearance of the trees from the point of view of colour and density of foliage and of general vigour and size showed no obvious differences due to treatment.

An indication of size of tree as affected by treatment was procured by analysing statistically the data for the circumferences of trunks of trees. An analysis of variance of the data showed no significant difference in the circumferences due to treatment during any of the five years. However, when

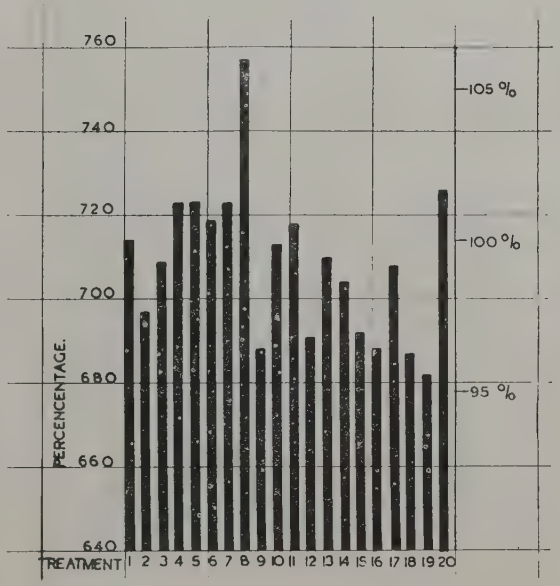


Diagram IX.
Moisture in 1936 pulp, expressed on dry weight basis.

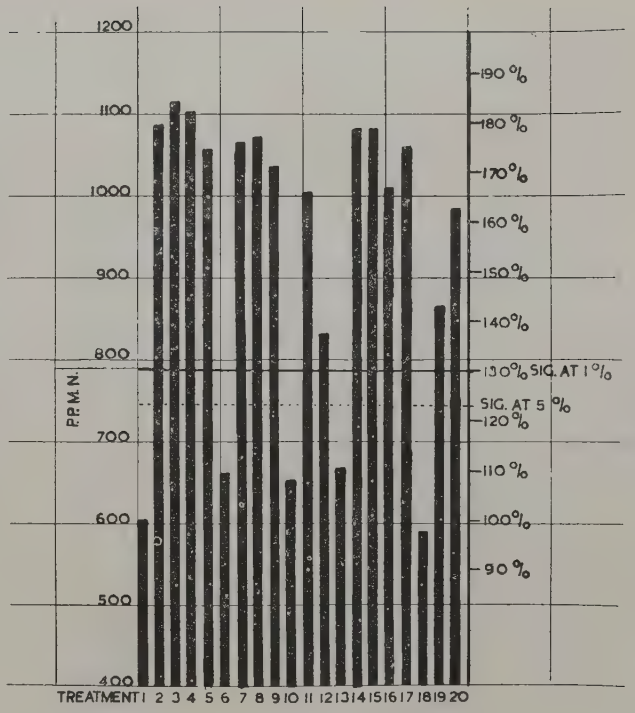


Diagram X.
Total Nitrogen in juice (1936).

the circumference data were adjusted for 1931, the pre-treatment year, then differences due to treatment were very definitely significant. In 1933 the treatment effect was significant at 5%, and in all the following years it was significant at 1%. The data for the various years are very similar, therefore only those for 1936, adjusted for 1931, are included here and represented in diagram VII. The rather surprising conclusion to be drawn from this diagram is that it is the control and the treatments without nitrogen that have shown the most marked increase in circumference, and presumably in growth generally. Treatments 1, 6, 10, 13 and 18, none of which included nitrogen, have thus resulted in the greatest increase in tree size. Treatments 19 and 20, which do include nitrogen, also show increases in circumference above the rest of the treatments, but these two cases, in which there was a luxuriant growth of the cover crop, may have been influenced by that crop in some obscure way ; at any rate no explanation can be offered at this juncture.

It will be noted that the differences in circumference illustrated in diagram VII are quite small, owing to the adjustment of the data for differences existing in the pre-treatment period, so that the actual differences due to treatment, although significant in a few cases, are unimportant from a practical point of view. Presumably, such differences as do exist with treatments not receiving nitrogen could be ascribed to the fact that such trees set only very small crops, and that the bulk of the relatively small amount of nitrogen present was available for growth. This, again, is an illustration of the tremendous drain which the setting and development of a crop exercise on the nitrogen reserves of a tree.

Rind thickness. The thickness of rind was determined only during 1936, the final year of this investigation, by the method described in an earlier paragraph. The analysis of variance of the data showed treatment to affect the thickness of rind significantly at 1%. The results are shown in diagram VIII.

Although relatively few of the vertical bars cross the significance lines in this diagram, there are two general conclusions which can be drawn with a fair degree of accuracy. Treatments 6, 10, 12, 13 and 18 are the only ones in which the average thickness of rind is less than that of the control and, including the control itself, these six treatments show thinner rinds than any of the other treatments. These six treatments are also the only ones in which no nitrogen was given (except treatment 12, in which only a very small amount of nitrogen was added), and it will be shown later that, for this reason, the trees have absorbed most phosphate. The six treatments resulting in the thinnest rind have the highest phosphate content, so that the indication is very strong that a high phosphate content results in a thin rind.

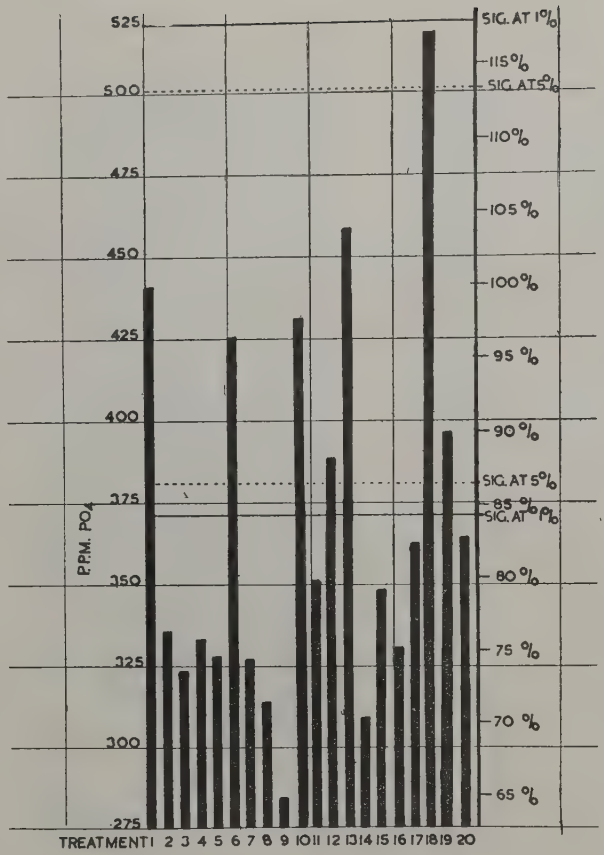


Diagram XI.
Total Phosphorus in the 1936 juice, expressed as PO_4.

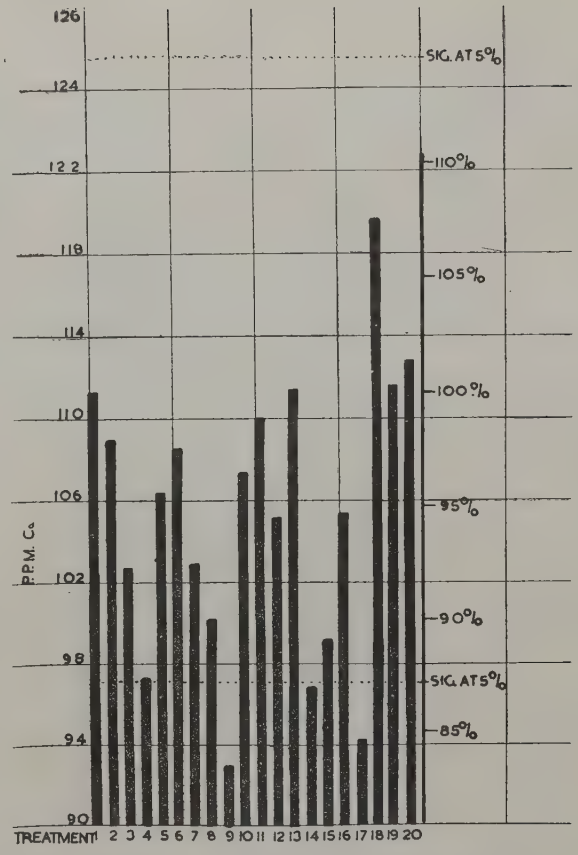


Diagram XII.
Calcium in juice (1936).

The remaining treatments all include a dressing of nitrogen, and in the majority of them the heavy application of six pounds of ammonium sulphate per tree. Furthermore, the three treatments 8, 9 and 14 which induced the most significantly thick rinds are those in which heavy applications of nitrogen (N_3) and little or no phosphate were given. The fruit from these plots will be shown later also to have absorbed the smallest amounts of phosphate.

The general conclusion indicated here is that low phosphate and high nitrogen is associated with thick rind and vice versa, but it will be shown later, where partial regression coefficients have been calculated, that the nitrogen effect is merely an indirect one, due to its depressing effect on absorption of phosphate, and that it is really the latter only that has a direct effect on the thickness of rind.

Juice content. As indicated earlier in this paper, the juice content was not determined in the orthodox fashion of calculating the percentage of juice by weight when rind is included ; this method was not used because any change in thickness of rind would alter the calculated juice percentage of the whole, whereas actually there may have been no change in the juice content of the pulp itself.

The data have been treated statistically throughout, but at no time have any of the treatments significantly affected the percentage moisture in the pulp. The results are presented in diagram IX.

In the literature (1, 35) it is mentioned that applications of nitrogen decrease the juice content of oranges, and that phosphate applications have the reverse effect. It should be kept clearly in mind that in the present paper it is the juice in the pulp only that has been determined, and although there were large fluctuations in nitrogen and phosphate content according to treatment, there was no effect on the moisture content of the pulp. This seeming contradiction will be explained later when partial regression coefficients are discussed, and when it will be shown that nitrogen depresses the absorption of phosphate and that a low phosphate content causes a thick rind. Because of these relationships, it will be clear why nitrogen and phosphate would affect the juice content when it is calculated on a whole fruit basis including rind.

Nitrogen content of juice. The nitrogen content of the juice was determined and the results for 1936 are presented in diagram X.

All nitrogen applications have significantly increased the nitrogen content of the juice. There is furthermore a significant difference between the nitrogen content of juice from plots receiving a light application of nitrogen (treatments 12 and 19) and those receiving a heavy application.

Reference was made earlier to the contentious question as to whether a leguminous cover crop appreciably increases the nitrogen content of all soils.

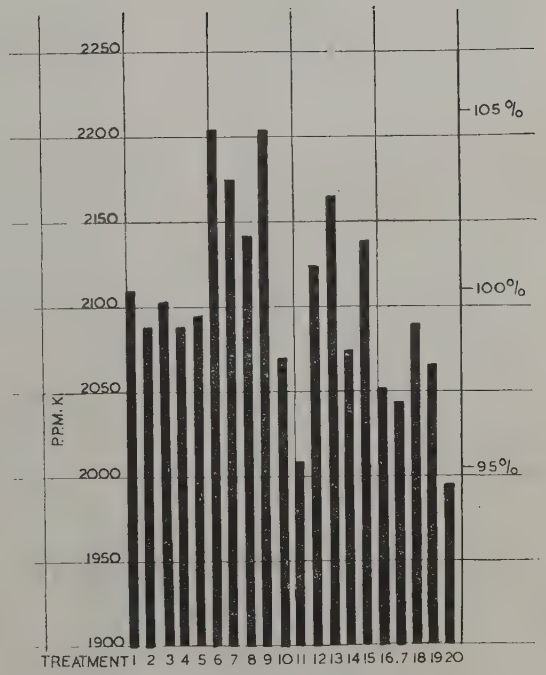


Diagram XIII.
Potassium in juice (1936).

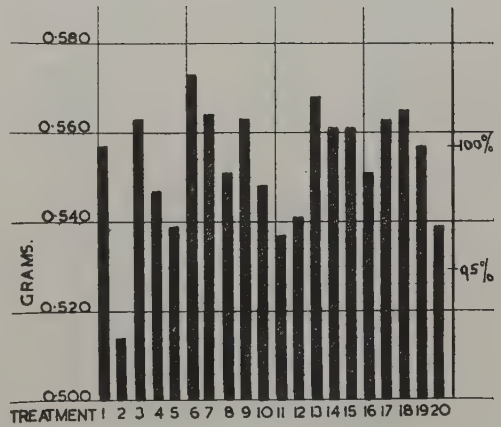


Diagram XIV.
Sulphate Ash weight of 100 cc. juice (1936).

Diagram X again raises this question. Treatment 18 is obviously no better off for nitrogen than the control plots or the others that have not received nitrogen ; also treatment 19, which provided for only a small amount of nitrogen and a leguminous cover crop, shows no higher nitrogen content of the juice than does treatment 12 in which no leguminous cover crop was included.

The exceedingly close relationship between the nitrogen content and treatment confirms the statements made earlier concerning the effect of treatment on number and weight of fruits.

Phosphorus content of juice. The samples of juice were analysed first for inorganic phosphorus and a second aliquot part was then ignited with magnesium nitrate and the total phosphorus determined. The organic phosphorus was calculated by difference. Only total phosphorus is presented in diagram XI in order to show the amount of phosphorus absorbed from the soil. The relationship between the inorganic and organic forms of phosphorus will be considered in a later section.

It will be noted that diagram XI shows exactly the reverse of the nitrogen figures presented in diagram X. Wherever nitrogen has been omitted (treatments 1, 6, 10, 13 and 18) or applied in small quantities only (treatments 12 and 19), the phosphorus content of the juice is high—higher in the former than in the latter. All treatments involving medium or high applications of nitrogen result in fruit juice with a phosphorus content very significantly below that from the rest of the plots.

This very significant relationship between nitrogen and phosphorus will be discussed further later in this paper when the various correlations are considered.

Calcium content of juice. The concentration of calcium in the juice for the 1936 season is presented in diagram XII. Although at first glance there appear to be large fluctuations in calcium content from treatment to treatment, it will be noticed from the figures on the left of the diagram that the concentrations in all the treatments vary only from 93 to about 120 p.p.m. Ca. There is no significance line for the 1% point because none of the fluctuations due to treatment is significant to this extent. Treatments 9, 14 and 17 show calcium contents below that of the control, the differences being significant at 5%. These low concentrations do not appear to be correlated with the particular treatments, however, and no explanation is offered at this stage. The concentrations are presented here, because the question of calcium content will be discussed again in a later paragraph dealing with correlations. In passing, however, attention should be drawn to treatment 16 which included annual applications of lime at the rate of 20 lb. $CaCO_3$ per tree ; these plots do not show any response in the calcium content of the fruit juice.

Potassium content of juice. The potassium concentration of juice in 1936 is illustrated by diagram XIII. As with calcium, the fluctuations in potassium

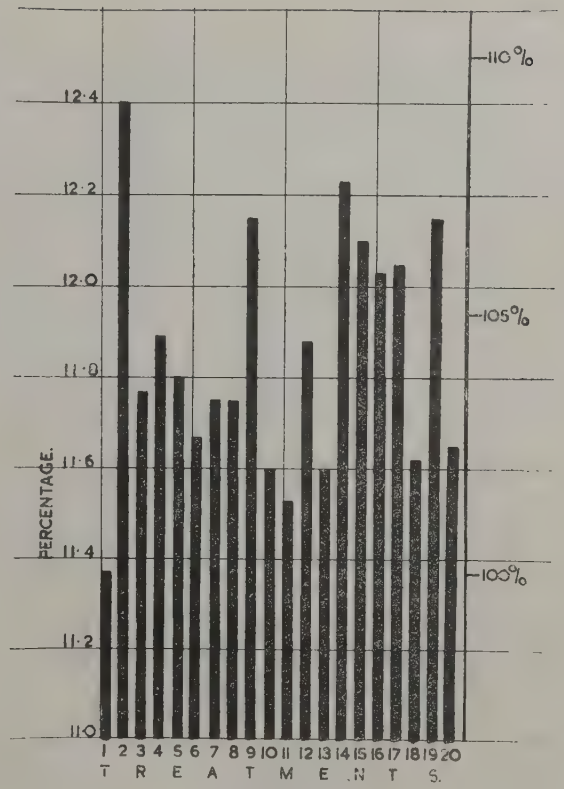


Diagram XV.
Total Soluble Solids in juice (1936).

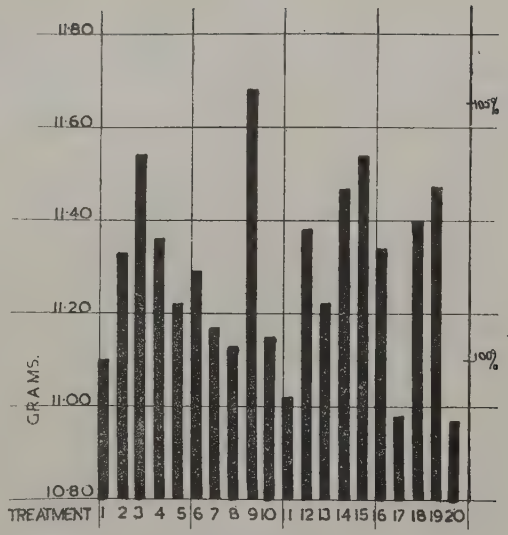


Diagram XVI.
Dry weight of 100 cc. juice (1936).

content are relatively narrow and there are no significant differences due to treatment. It can be assumed, however, that very little of the potassium applied with the treatments was available for absorption in the root zone because of the rapid fixation of potassium in the upper layer of soil.

The data presented here will be considered again later in the paragraphs concerned with correlations.

Ash weight of juice. The ash weight of juice was determined as indicated at the outset and the results are presented in diagram XIV. There are no significant differences in ash content due to differential treatment, but the data will be referred to again in the later paragraphs dealing with correlations and partial regression coefficients.

Sugar content of juice. The juice was analysed for total sugars, but as the statistical analysis of the data produced no significant differences due to treatment, it is felt that they need not be reproduced here. The approximate quantities of sugars present in the juice can be gauged by the refractometer readings referred to in the next paragraph, which represent total soluble solids of which sugars form the major part. Further consideration will be given to the data later in the paragraphs dealing with correlations.

Total soluble solids in juice. The total soluble solids as determined by a refractometer are represented for 1936 in diagram XV. It will be noted that there are no significance lines across this diagram, thus showing that the differential treatments had no significant effect on the soluble solids content of the juice. In view of the lack of significance with sugar content and also with ash content, it might be expected that total soluble solids also would not show any significant differences due to treatment. These data also will be referred to again when discussing correlations in a later paragraph.

Dry weight of juice. The dry weight of juice reflects much the same picture as the concentrations of total soluble solids determined with the refractometer. The results are presented in diagram XVI and will be discussed again later when the various correlations are considered. It will suffice at this stage to point out that treatment had no significant effect on the dry weight of juice.

Acid content of juice. It will be noted from diagram XVII that very few of the vertical bars representing acid content of juice cross the 5% significance line and that only one crosses the 1% significance line. However, it appeared from this diagram as if the treatments with nitrogen showed a generally higher acid content than the rest, hence an analysis of variance was calculated, grouping together all the treatments receiving nitrogen (2, 3, 4, 5, 7, 8, 9, 11, 12, 14, 15, 16, 17, 19 and 20) and all those without nitrogen (1, 6, 10, 13 and 18). As a result of this analysis the "Z" value for nitrogen treatments versus the

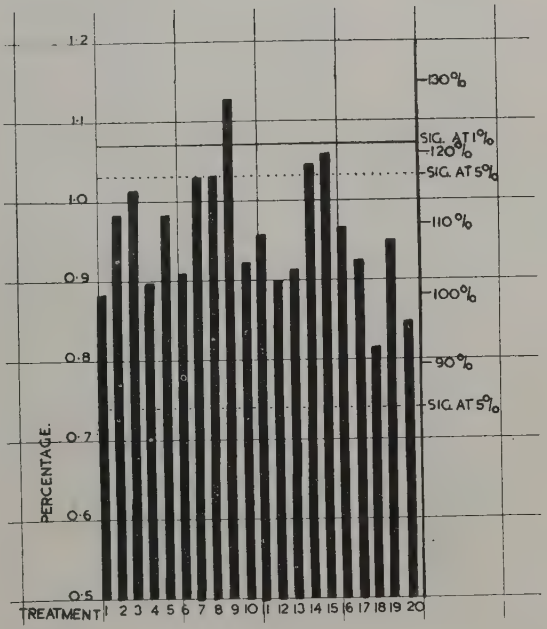


Diagram XVII.
Acid content of 1936 juice, expressed as Citric acid.

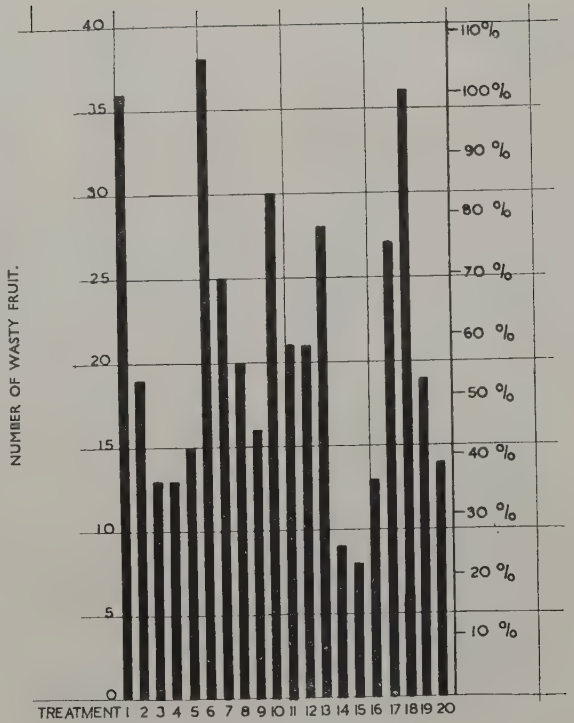


Diagram XVIII.
Total number of waste fruit per treatment in packed cases (1936)

rest was markedly significant at 1%. It can accordingly safely be concluded that nitrogen applications to these trees caused the fruit to have a higher acid content. The question as to whether this effect is a direct or an indirect one will receive consideration in the later paragraphs dealing with correlations.

Wastage during storage. Diagram XVIII represents the 1936 results of wastage counts in six cases of oranges from each treatment. It will be noted that no horizontal significance line is indicated because the analysis of variance of the data showed an insignificant "Z" value. This diagram shows rather strikingly, however, that the five treatments (1, 6, 10, 13 and 18) which had not included nitrogen, are also the five which show the greatest amount of wastage. For this reason an analysis of variance was calculated, when all the nitrogen treatments were grouped together and compared with the non-nitrogen treatments. In this analysis the "Z" value was significant at 1%; in other words, the nitrogen treatments significantly decreased the amount of wastage in the fruit. This point also will be considered further in the following paragraphs dealing with correlations.

CORRELATION AND REGRESSION COEFFICIENTS.

In the preceding paragraphs the results of differential manurial treatments on the crop, composition and other characters of oranges have been reported. The data so acquired have been further analysed with a view to determining what correlations, if any, exist between the various characteristics. Table II gives the results of such correlation coefficients, which are to be interpreted as correlations which exist *irrespective* of differential treatments. Usually only those correlations significant at 1% will be considered in the following paragraphs.

The units used in the partial regression coefficients given below, are the same as those used in the previous diagrams.

Acid Content.

Acid × Moisture. Coefficient No. 1 shows a negative correlation, significant at 1%, between acid content of juice and moisture content of pulp. This presumably means merely that when the juice content of an orange is high its acid content is relatively low due to dilution.

Acid × Thickness of rind. Coefficient No. 16 shows that the acid content is significantly and positively correlated at 1% with the thickness of the rind. As these two factors cannot very well be directly correlated, the explanation for the correlation must lie in some third factor with which both of these characters are strongly correlated. Coefficients 20 and 33 give the necessary explanation. Here phosphorus content is shown to be negatively and significantly correlated at 1%, first with acid content and then with thickness of rind.

TABLE II.

Correlation Coefficients of Juice Components, Juice Content (Moisture) of Pulp, Thickness of Rind and Wastage.

	Acid.	Thickness of rind.	Wastage.	Total Soluble Solids.	Total Phosphorus.	Inorganic Phosphorus.	Organic Phosphorus.	Sugar.	Nitrogen.	Potassium.	Calcium.	Ash.	Dry Weight.
	(1)	(2)	(3)	(4)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(15)
Moisture content of pulp	−0·416**	−0·165	0·297**	0·605**	0·110	0·082	0·054	−0·499**	−0·367**	−0·349**	0·292**	−0·346**	0·539**
		(16)	(17)	(18)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(28)	(29)
Acid ..		0·587**	−0·458**	0·555**	−0·541**	−0·547**	0·049	0·247*	0·581**	0·363**	−0·514**	0·227*	0·457**
			(30)	(31)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(41)	(42)
Thickness of rind ..			−0·268**	0·274**	−0·418**	−0·465**	0·133	0·096	0·406**	0·314**	−0·221*	0·166	0·268**
				(43)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(53)	(54)
Wastage ..				0·440**	0·348**	0·401**	−0·140	−0·222*	0·530**	0·252*	0·568**	−0·188	−0·401**
Total Soluble Solids ..					(56) 0·133	(57) 0·185	(58) 0·124	(59) 0·765**	(60) 0·561**	(61) 0·507**	(62) −0·443**	(64) 0·473**	(65) 0·830**
Total Phosphorus						(76) 0·895**	(77) 0·165	(78) −0·047	(79) −0·385**	(80) 0·147	(81) 0·294**	(83) 0·207*	(84) −0·170
Inorganic Phosphorus							(85) −0·292**	(86) −0·121	(87) −0·494**	(88) 0·103	(89) 0·345**	(91) 0·107	(92) −0·249*
Organic Phosphorus								(93) 0·169	(94) 0·267**	(95) 0·086	(96) −0·134	(98) 0·208*	(99) 0·187
Sugar ..									(100) 0·344**	(101) 0·339**	(102) −0·159	(104) 0·436**	(105) 0·797**
Nitrogen ..										(106) 0·399**	(107) −0·474**	(109) 0·224*	(110) 0·512**
Potassium ..											(111) −0·306**	(113) 0·641**	(114) 0·489**
Calcium ..												(116) −0·231*	(117) −0·285**

* 5% significance. ** 1% significance.

It therefore seems justifiable to conclude that the correlation between acid content and thickness of rind is an indirect one.

Acid × Wastage. Coefficient No. 17 shows a very strong negative correlation, significant at 1%, between acid content and wastage. This may possibly be a direct correlation, as it is conceivable that the higher the acid content the less favourable the medium may become for fungus growth, hence less wastage. It is possible, however, that the acid content may be associated with wastage only indirectly, in the following manner: Acid content is negatively correlated with calcium content (coefficient No. 26) which, in turn, is positively correlated with wastage (coefficient No. 51). As a matter of fact it will be shown later, under the heading, "Wastage", where partial regression coefficients have been calculated for all the factors correlated with wastage, that this relationship between acid content and wastage is indirect.

Acid × Total soluble solids. The significant positive correlation between these two factors (coefficient No. 18) might have been expected, because the acid present is always one of the components included in the determination of total soluble solids.

Acid × Total P, N, K, Ca and Dry weight. Acid content is correlated negatively with total phosphorus (No. 20), positively with nitrogen (No. 24) and potassium (No. 25), negatively with calcium (No. 26) and positively with dry weight (No. 29). As there is insufficient actual information available concerning the physiological influence of these factors to make it possible to interpret the above correlations with certainty, partial regression coefficients of acid content and total phosphorus, nitrogen, potassium, calcium and dry weight were calculated.

From Fisher's "t" table it was determined that for any of these partial regression coefficients to be significant, their "t" values should exceed 1·987 at the 5% point and 2·634 at the 1% point.

The partial regression coefficients and "t" values of the above factors are the following:—

	Partial Regression Coefficients.	*"t" Values.*
Acid and P	$-0{\cdot}001{,}039 \pm 0{\cdot}000{,}195$	5·322**
,, ,, N	$0{\cdot}000{,}163 \pm 0{\cdot}000{,}097$	1·675
,, ,, K	$0{\cdot}000{,}251 \pm 0{\cdot}000{,}092$	2·717**
,, ,, Ca	$-0{\cdot}002{,}034 \pm 0{\cdot}000{,}811$	2·510*
,, ,, Dry weight	$0{\cdot}024{,}154 \pm 0{\cdot}016{,}269$	1·485

It will be noted that, of the five factors tested, an influence significant at 1% is exerted only by the phosphorus content (negatively) and by the potassium content (positively), although the effect of calcium is also significant at 5%.

From the above it is to be concluded that although nitrogen content is consistently positively correlated with acid content, and the nitrogen applications reported on in earlier paragraphs are also associated with increased acid content, the high acid content of the fruit is not directly attributable to high nitrogen content. Rather, it is the low phosphorus content (which will be shown by later partial correlations to be induced by high nitrogen) which is the cause of the increased acid content. It is thus conceivable that oranges may have a high nitrogen content and still exhibit no more than a normal acid content, provided that the phosphorus content of the fruit is also high.

The potassium content is positively correlated with acid content, and from the above calculation of partial regression coefficients it is evident that potassium has a direct influence on acid content and is not merely indirectly correlated with it.

Calcium is associated with acid content and in a negative manner, but this influence is significant only at the 5% point. However, the same effect of calcium is reported by other workers (18), so that this significance at 5% can most probably be accepted as presenting a true influence of calcium on acid content.

Thickness of Rind.

Rind × Total soluble solids. Coefficient No. 31 shows a positive correlation, significant at 1%, between these two factors. As it is not easily conceivable how a high concentration of total soluble solids could induce a thick rind, this correlation must for the time being be considered an indirect one.

Rind × Total P, N, K, Ca and Dry weight. The thickness of rind is negatively correlated with total phosphorus (No. 33) and positively with nitrogen (No. 37), potassium (No. 38) and with dry weight (No. 42).

A calculation of partial regression coefficients of thickness of rind and the above factors gave the following results, where Fisher's "t" table requires a value of 2·634 for significance at 1% and of 1·987 at 5%.

		Partial Regression Coefficients.	*"t" Values.*
Thickness of rind and	P	$-0{\cdot}087{,}381 \pm 0{\cdot}020{,}132$	4·341**
,, ,, ,, ,,	N	$0{\cdot}012{,}486 \pm 0{\cdot}010{,}047$	1·240
,, ,, ,, ,,	K	$0{\cdot}031{,}278 \pm 0{\cdot}009{,}527$	3·283**
,, ,, ,, ,,	Ca	$0{\cdot}066{,}342 \pm 0{\cdot}083{,}537$	0·794
,, ,, ,, ,,	Dry weight	$0{\cdot}574{,}476 \pm 1{\cdot}676{,}59$	0·343

Of the four factors it appears that only phosphorus content and potassium content have a direct effect on thickness of rind, the former being negatively and the latter positively associated.

It is the practical citrus grower's experience generally that heavy applications of nitrogenous fertilizers cause the fruits to have thick rinds. From the above it would appear that the nitrogen effect is an indirect one and that its influence in retarding absorption of phosphorus (which will be further proved later) is the real reason for the thick rind. It would be reasonable to assume from the above that a high nitrogen content in the soil or fruit would not induce thick rinds provided that large quantities of phosphorus were also available and absorbed. The remarks concerning the relationship of nitrogen and phosphorus made in the previous paragraphs dealing with acid content would also apply here.

The lack of significance for dry weight in the above Table confirms the opinion expressed in the preceding paragraph, namely that the correlation of thickness of rind with total soluble solids (in this case, dry weight) is merely an indirect one.

Wastage.

From Table II it will be seen that the following factors are correlated, at 1%, with wastage: Moisture content of pulp (+), acid (−), thickness of rind (−), total soluble solids (−), total phosphorus (+), nitrogen (−), potassium (−, actually only at 5%, but included here because of its alleged importance in connection with storage quality), calcium (+) and dry weight (−).

Because it was impossible to assess the importance of the above factors separately and to determine which correlations were direct or indirect, the tremendous task of solving partial regression coefficients of wastage and the above nine variables was decided upon. The coefficients for the nine factors were as follows when Fisher's "t" table requires their "t" values to exceed 1·987 for significance at 5% and 2·634 at 1%.

	Partial Regression Coefficients.	*"t" Values.*
Wastage and moisture in pulp	0·000,849 ± 0·007,3	0·116
,, ,, acid	−0·499,989 ± 4·467,9	0·112
,, ,, thickness of rind	−0·004,305 ± 0·414,0	0·010
,, ,, total soluble solids	−0·010,144 ± 1·094,6	0·009
,, ,, Total P	0·009,124 ± 0·008,9	1·025
,, ,, N	−0·007,533 ± 0·003,7	1·998*
,, ,, K	−0·000,694 ± 0·003,7	0·186
,, ,, Ca	0·125,089 ± 0·033,0	3·663**
,, ,, Dry weight	−0·969,337 ± 0·931,2	1·041

The only factor which at 1% significantly influences wastage in these oranges was the calcium content. The more calcium present in the fruit the more serious was the wastage due to mould growth.

The value for nitrogen in the above Table is significant only at 5% and should accordingly be accepted with reserve. By referring forward to the paragraph dealing with the effect of treatment on wastage, however, it will be noted that "N-treatments versus the Rest" gave a "Z" value significant at 1%, so that combined with the above partial regression coefficient for wastage and nitrogen, significant at 5%, the conclusion that high nitrogen induces low wastage is more justified.

Sugar Content.

Sugar × Moisture content of pulp. Coefficient No. 9 in Table II shows a negative correlation, significant at 1%, between sugar content of juice and moisture content of pulp. It is assumed that this correlation is to be attributed to the dilution effect of an increased moisture content of the pulp on the concentration of the sugar.

Sugar × Total soluble solids. This correlation (No. 59) is to be expected when it is considered that sugar is the principal constituent of the total soluble solids. The same remarks hold for coefficients Nos. 105 and 65 where sugar and total soluble solids are very highly correlated with dry weight.

Sugar × N, K and Ash. Sugar content is significantly and positively correlated with nitrogen (coefficient No. 100), potassium (No. 101) and with ash (No. 104). In order to determine which of these three factors directly affect sugar content, partial regression coefficients were calculated of sugar content and nitrogen, potassium and ash content. The "t" values of these regression coefficients must exceed 2·634 to be significant at 1%, and 1·987 at 5%. They are shown in the following Table.

	Partial Regression Coefficients.	*"t" Values.*
Sugar and N	0·001,256 ± 0·000,467	2·692**
,, ,, K	−0·000,064 ± 0·000,602	0·106
,, ,, Ash	8·190,350 ± 2·494,180	3·284**

The above Table shows that only nitrogen content and ash content influence sugar content, potassium does not affect sugar content directly. The apparent affect of potassium on sugar content, as indicated by coefficient No. 101, must be assumed to be an indirect one, brought about by the positive correlation between potassium and nitrogen (No. 106) and between nitrogen and sugar (No. 100).

The above regression coefficients mean, furthermore, that there is some constituent or constituents in the ash other than N or K or the other components indicated in Table II which significantly affects sugar content of the juice in a

positive manner. Just what these constituents are is unknown at present, but the problem is being further investigated.

Total Soluble Solids.

T.S.S. × Moisture in pulp. The significant negative correlation (No. 4) shown between these two factors in Table II is presumably due merely to the dilution effect of increased moisture content on concentration of total soluble solids. The same remark would apply to coefficient No. 15, where dry weight of juice is negatively correlated with moisture content of pulp.

T.S.S. × N, K, Ca and Ash. Total soluble solids content is positively correlated with nitrogen content (No. 60), potassium (No. 61) and ash (No. 64), and negatively correlated with calcium content (No. 62). In order to disentangle these correlations and determine which of the factors have an actual effect and which merely an indirect one on T.S.S. content, partial regression coefficients were calculated as before. According to Fisher's "t" table the "t" values of these regression coefficients must exceed 1·987 to be significant at 5% and 2·634 at 1%.

	Partial Regression Coefficients.	*"t" Values.*
T.S.S. and N	0·001,946 ± 0·000,481	4·050**
,, ,, K	0·000,754 ± 0·000,563	1·338
,, ,, Ca	−0·008,470 ± 0·004,481	1·890
,, ,, Ash	6·174,765 ± 2·335,530	2·644**

These partial regression coefficients show much the same results as those previously obtained for sugar content, because the largest part of the total soluble solids is made up of sugar. In other words, potassium content does not significantly affect total soluble solids content, whereas high nitrogen content is directly associated with high concentration of soluble solids. As with sugar, there appears to be some undetermined factor in the ash which, when present in increased quantities, causes an increase in total soluble solids.

Moisture Content of Pulp.

Moisture content × N, K, Ca, Ash and Dry weight. Moisture content of pulp is negatively correlated with nitrogen (No. 10), potassium (No. 11), ash (No. 13), dry weight (No. 15) and positively with calcium (No. 12). The partial regression coefficients of moisture content of pulp and the above factors are shown in the following Table, where the "t" values of the partial regression coefficients should exceed 1·987 to be significant at 5% and 2·634 at 1%.

	Partial Regression Coefficients.	*"t" Values.*
Moisture content and N	$-0{\cdot}031{,}234 \pm 0{\cdot}053{,}673$	0·582
,, ,, ,, K	$-0{\cdot}022{,}318 \pm 0{\cdot}057{,}646$	0·387
,, ,, ,, Ca	$0{\cdot}517{,}220 \pm 0{\cdot}456{,}87$	1·132
,, ,, ,, Ash	$-111{\cdot}584{,}428 \pm 255{\cdot}708$	0·436.
,, ,, ,, Dry weight	$-36{\cdot}107{,}505 \pm 9{\cdot}971{,}6$	3·621**

The above "t" values show that none of the factors is associated directly with moisture content of pulp except dry weight of juice. It is assumed, however, that this negative relationship between moisture content of pulp and dry weight of juice is merely due to the dilution effect of increased moisture content on the total soluble solids which comprise the dry weight.

Nitrogen Content.

N × Total P, K and Ca. Of the significant correlations which deserve consideration and which may directly affect the nitrogen content of the juice, there are total phosphorus (No. 79), potassium (No. 106) and calcium (No. 107).

The following Table shows the partial regression coefficients and "t" values for the above factors, when the "t" values must exceed 1·987 to be significant at 5% and 2·634 at 1%.

	Partial Regression Coefficients.	*"t" Values.*
Nitrogen and total P	$-0{\cdot}841{,}310 \pm 0{\cdot}199{,}374$	4·220**
,, ,, ,, K	$0{\cdot}379{,}302 \pm 0{\cdot}087{,}838$	4·318**
,, ,, ,, Ca	$-2{\cdot}429{,}708 \pm 0{\cdot}873{,}150$	2·783**

From the above it appears that all three of the factors, P, K and Ca, have a direct influence on the amount of nitrogen present in the juice.

The more phosphorus or the more calcium present, the less nitrogen is absorbed into the fruit, and vice versa. In the earlier paragraphs dealing with differential treatments in the field, the effect of phosphorus and calcium applications on the absorption of nitrogen was not evident, presumably because insufficient phosphorus and calcium were available for absorption in relation to the larger quantities of nitrogen. The effect of nitrogen on absorption of phosphorus was, however, very marked, because the nitrogen was present in relatively larger quantities than the phosphorus. As indicated in earlier sections also, it might be assumed that if the amount of available phosphorus was sufficiently increased, relatively to nitrogen, then the phosphorus would in turn cause less nitrogen to be absorbed.

The potassium content is associated with nitrogen content in a positive manner, so that increased quantities of K absorbed are directly associated with increased N absorption.

PHOSPHORUS CONTENT.

Total P × N and Ca. Total phosphorus is negatively correlated with nitrogen (No. 79) and positively with calcium (No. 81). The calculation of partial regression coefficients of total P and N and Ca gave the following results, when the "t" values had to exceed 1·987 to be significant at 5% and 2·634 at 1%.

	Partial Regression Coefficients.	*"t" Values.*
Total P and N	$-0{\cdot}137{,}727 \pm 0{\cdot}046{,}858$	2·939**
,, ,, ,, Ca	$0{\cdot}605{,}938 \pm 0{\cdot}453{,}73$	1·325

The above confirms the relationship between N and P referred to several times in earlier paragraphs; the higher the N content the lower the P content, and vice versa.

The positive correlation between Ca and total P (No. 81) must be assumed to be an indirect one, to be explained by the negative correlation between Ca and N (No. 107) and the negative correlation between N and total P (No. 79).

Inorganic P and organic P. By glancing through the coefficients for total P and also for inorganic P it will be noticed that they are always of the same sign and their significance trends are the same. This is to be expected when it is realized that most of the total P is in the inorganic form and the organic P is present in relatively small quantities. This is further borne out by coefficient No. 76 which shows a positive correlation, significant at 1%, between total P and inorganic P.

The negative correlation between organic P and inorganic P (No. 85) might be expected, as these two are the components of one whole, viz. total P.

Coefficients 87 and 94 are of particular interest as they bring out the relationship between nitrogen content and the two forms of P. No. 87 shows a negative correlation between N and inorganic P whereas No. 94 shows a positive correlation between N and organic P. Thus, it appears that a high nitrogen content is necessary for the synthesis of phosphorus-containing compounds, presumably proteins, and when nitrogen content is low more of the phosphorus remains in the inorganic form. This important relationship between N content and the synthesis of P-containing organic compounds is even more clearly illustrated in Table III, where it is shown that wherever the N content

TABLE III.

Phosphorus Content of Juice expressed as p.p.m. PO_4.

TREATMENTS.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	r
Total Phosphorus	442	341	323	333	329	426	327	314	285	432	352	389	458	310	347	331	363	518	397	365	−0·925**
Inorganic Phosphorus	362	241	221	228	234	319	226	213	188	355	259	288	359	206	237	236	251	434	296	270	−0·938**
Organic Phosphorus	80	100	102	105	95	107	101	101	97	77	93	101	99	104	110	95	112	84	101	95	0·607**
Total Nitrogen	605	1,089	1,118	1,104	1,057	663	1,067	1,072	1,039	654	1,006	833	669	1,082	1,082	1,011	1,061	590	866	986	

r = treatment correlations between Nitrogen and Phosphorus. (These should not be confused with the r's in Table II, which are correlations irrespective of treatment.)

is high the organic P content is also high, even though the total amount of P is simultaneously low.

Potassium Content.

K × total P, N, Ca and Ash. Partial regression coefficients were calculated of K and total P, N, Ca and ash. For significance the "t" values have to exceed 1·987 at the 5% point and 2·634 at the 1% point.

	Partial Regression Coefficients.	*"t" Values.*
K and total P	0·433,829 ± 0·195,710	2·217*
,, ,, ,, N	0·310,512 ± 0·089,119	3·484**
,, ,, ,, Ca	−0·927,972 ± 0·826,250	1·123
,, ,, ,, Ash	2,243·656 ± 358·796	6·253

The above partial regression coefficients show that nitrogen and ash content directly influence K content; the higher the N or ash the higher is the K content. This relationship between K and N has also been shown in the partial regression coefficients calculated for nitrogen content in an earlier paragraph. According to the significant "t" value for K and ash above, there appears to be some component in the ash, other than those determined, which also has a direct influence on K absorption.

Considering the frequent references in the literature (18, 17) to the reciprocal effect of Ca and K on the absorption of each other, it seems strange that the above Table of partial regression coefficients does not show a direct influence of Ca on absorption of K. The explanation of this may lie in the fact that many investigators have had insufficient data concerning ions other than the cations with which they were dealing to make it possible to determine by partial regression coefficients which ion really had a direct and which had merely an indirect influence on another ion.

In the present case, for instance, the K content is positively correlated with nitrogen (No. 106), ash (No. 113) and dry weight (No. 114) and negatively with Ca (No. 111). The partial regression coefficients show, however, that the Ca has no direct effect on K. This will be explained in the next paragraph, dealing with Ca content, where the partial regression coefficients will prove that it is the N content which influences the Ca absorption in a negative fashion. It is, accordingly, because N influences Ca and also K that Ca is correlated with K, and this correlation must therefore be looked upon as being an indirect one.

The "t" value of the partial regression coefficient of K and total P shows a relationship between these two factors which is significant at 5%. This is a most unexpected significance when the other correlations discussed here

are considered, and when coefficient No. 80, in Table II, shows quite an insignificant correlation between these two factors. Until more information is available on this point, the above "t" value, significant at 5%, must be accepted with considerable reserve, as it may be due to chance. This insignificant correlation (No. 80) was included in this above calculation of partial regression coefficients merely to bring about uniformity with similar calculations for calcium content given below.

Calcium Content.

Ca × total P, N, K and Ash. Calcium content is positively correlated with total phosphorus (No. 81) and negatively with nitrogen (No. 107), potassium (No. 111) and ash (No. 116; significant at 5% only, but included here in order to bring about uniformity with the calculation of partial regression coefficients of K given above). The partial regression coefficients and their "t" values of the above factors were calculated and are shown in the following Table. For significance at 5% the "t" values must exceed 1·987 and at 1%, 2·634.

	Partial Regression Coefficients.	*"t" Values.*
Calcium and total P	0·052,473 ± 0·024,711	2·123*
,, ,, ,, N	−0·031,599 ± 0·011,488	2·751**
,, ,, ,, K	−0·014,734 ± 0·013,118	1·123
,, ,, ,, Ash	−53·897,998 ± 53·764,5	1·002

The effect of nitrogen on calcium is most marked. The higher the N content the lower the Ca content, and vice versa. In the above Table and in the preceding one dealing with K, as well as in the Table of correlations (Table II), it will be noted that the N content is associated with the K content in a positive manner and with Ca content in a negative manner. This would prove the negative correlation between Ca and K (No. 111) to be an indirect one, due to the association of Ca and K with N.

As with K, in the preceding paragraph, so now with Ca, the partial regression coefficient of Ca and total P is also significant at 5%. Unfortunately, in this instance too, it is not now possible to assess the value of this significance or to interpret it.

Other Correlations.

Such other correlations as appear in Table II and have not been discussed above are either insignificant or, where there is significance, the correlation is obvious and predictable.

DISCUSSION.

During most of the detailed statistical analysis reported on in this paper only the results of the final year of the investigation have been used. The reason for this is that during the final year all analyses were conducted separately on the material from each replicate of each treatment, so that the statistical interpretation would be as accurate as possible. During the first four years, analyses for the various elements were made only on composite samples representing each treatment and not each replicate of each treatment ; for them, correlations were also calculated and they agreed in all essentials with those presented in Table II, but it was felt that for final conclusions the much more laborious but complete analyses as indicated should be employed.

This paper presents rather vividly the great value of modern statistical methods in the interpretation of biological results. Although many of the conclusions confirm what has been found previously by other investigators, it is felt that even such conclusions are now placed on a more firm and final basis than has been possible by other research workers who either did not have sufficient data or did not acquire them in a manner essential for statistical analysis by the methods employed here.

Various investigators (35, 18, 1, 12, 14, 15, 24, 32, 33, 36, 39) have reported the positive correlation between K and acid and the negative correlation between P and acid. It has been shown in the foregoing correlation coefficients (Table II) that there is also a consistent positive correlation between N and acid content ; it was often due to good fortune or lack of sufficient data that some investigators drew the correct conclusions, because only by the use of partial regression coefficients, as employed here, could the correlations be resolved into those which are directly and those which are indirectly associated, owing to some third common correlation. For instance, it has been reported (1) that applications of ammonium sulphate to orange trees caused an increased acid content in the fruit, except where large quantities of kraal manure were also added. In this instance the acid content can now be explained by the low phosphorus absorption in the first case, where N has been added, and the addition of phosphorus in the manure or the greater availability of phosphorus caused by the manure, in the second case. Other workers (5, 22, 23, 24) also have reported that applications of nitrogenous fertilizers induce an increased acid content in the crop, but this is to be interpreted as merely an indirect effect of the nitrogen, and the direct effect is due to a reduced absorption of P.

The partial regression coefficients of wastage and the many factors correlated with it, form another good illustration of how essential it is to have as complete data as possible before conclusions are drawn, and how necessary it is to distinguish between indirect and direct effects by means of partial regression

coefficients. It has been claimed, for instance, that high acid content of fruit is associated with low wastage (2), and the implication is that this is cause and effect ; also that low K and low P cause poor storage quality (3, 6) ; the same correlations are shown in Table II, but the partial regression coefficients show that both these factors affect wastage only indirectly. With apples (20), a high sucrose and low nitrogen content was found to favour keeping quality ; a similar correlation is shown for sugar and total soluble solids in Table II, but the partial regression coefficients show these correlations also to be indirect as far as they affect wastage of navel oranges ; on the other hand, with navel oranges, a low N content was always correlated with a high percentage of wastage. Wallace (38) claims that from the data available, no general statement can be made concerning the relationship of any chemical constituent with storage qualities ; the importance of Ca in metabolism has, however, been emphasized by many investigators (27, 28, 34), and the influence of Ca content on wastage of oranges, as illustrated by the partial regression coefficients given above, is very striking.

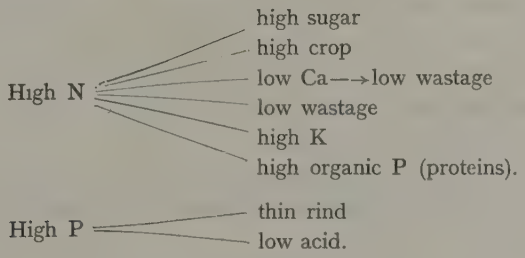
In Table II a significant positive correlation is shown between K and sugar content. A similar relationship is reported for Satsuma oranges in Japan (32), but the data concerning the latter have not been subjected to intensive statistical analysis, whereas the partial regression coefficients reported in this paper show that the K × sugar correlation is an indirect one only. Contrary to the result indicated in coefficient No. 100 in Table II, a high N content in grapefruit in Trinidad (18) is claimed to be correlated with a low sugar content ; since the results with grapefruit were not capable of statistical interpretation, it is doubtful whether this apparent contradiction is a real one.

Although none of the factors determined in this investigation shows a direct effect on the moisture content of the pulp, other workers have reported an increase in juice content due to phosphate application (1, 35), and a decrease in juice due to nitrogen applications (1). It must be remembered, however, that these workers have determined juice content as a percentage of the whole fruit, including the rind, whereas in the work reported here, the actual moisture content of the pulp was determined, excluding the rind. The explanation for the effect of P and of N on the juice content above referred to is, then, to be sought in the effect of P and of N on the thickness of rind and not on the actual juice content of the pulp itself. From the correlations and partial regression coefficients reported in earlier paragraphs it is seen that a high N content causes a low P content which, in turn, causes a thick rind. If, then, the weight of rind is included in a calculation of juice content, as was done by the above workers, it is obvious that a high N application will appear to decrease, and a high P application to increase, the juice of the orange as a whole, whereas the juice content of the pulp, as such, would most probably not have altered at all.

Certain interactions of K, P, N and Ca have been mentioned by many investigators during the last five or six years. Some of these interactions are so very marked that it does not require detailed statistical analysis to prove them, but in the majority of cases it is felt that the data presented on this subject in this paper have finally substantiated what could not have been much more than hypothesis heretofore. Furthermore, most of the conclusions concerning interactions have been drawn by other workers from simple correlations, whereas some such simple correlations are shown in this paper to be indirect, due to some third correlation common to the two first factors. The reciprocal relationship between N and P has been reported on by various investigators (18, 26, 9, 15, 16, 25, 29, 30), but the direct relationship between N and K, as presented here, is seldom satisfactorily reported in the literature (37, 4, 18), and so is the reciprocal relationship between N and Ca (18, 4, 26).

CONCLUSION.

The above report emphasizes throughout the importance of a balanced nutrient solution. In this connection the general conclusion is that, although fundamentally one ion is as important as another, the two most important ions that have to be present in correct proportions and in considerable quantities are $-NO_3$ and $\equiv PO_4$. The proportion and concentration should be such that considerable quantities of both ions should be absorbed, and this would have the following effects:—



SUMMARY.

The importance of plot design and statistical analysis of data is illustrated throughout this paper. The most important conclusions are the following:—

1. Applications of $(NH_4)_2SO_4$ to soil induced very marked increase in weight of crop and number of fruits. There was no significant difference in crop, however, between applications of 2, 4 and 6 lb. $(NH_4)_2SO_4$ per tree.

2. A leguminous cover crop did not increase the N content of the soil, or, accordingly, the size of crop.

3. Applications of superphosphate, potassium sulphate and lime did not affect size of crop.

4. The amount of out-season fruit was not affected by any of the treatments. The size of an in-season crop, however, shows a significant negative correlation with the following out-season crop. This can be explained on the basis of amount of nutritional reserves.

5. Although applications of nitrogenous fertilizers caused an increased crop, the increase in tree size did not exceed that of the control, rather the reverse.

6. Fruits from all plots of all treatments were analysed for P, K, Ca, N, Ash, Dry Weight, Sugar, Total Soluble Solids, Acid, Thickness of Rind and Wastage due to mould.

7. Correlations and partial regression coefficients were calculated for all factors before final conclusions were drawn.

8. A high P content and probably also a high Ca content is associated with a low acid content. On the other hand, a high K content causes a high acid content.

9. A high K content causes a thick rind of oranges, whereas a high P content induces a thin one.

10. A high Ca content causes an increase in the amount of wastage due to mould during storage. Nitrogen has the reverse effect.

11. None of the factors determined has any effect on sugar content except N, which increases sugar content with increased N content, and ash, which has a similar effect.

12. Remarks similar to those for sugar apply to total soluble solids.

13. The juice content of the pulp is not affected directly by any of the factors determined.

14. There is a reciprocal relationship between P and N, and between Ca and N ; there is also a direct positive relationship between K and N, and between K and ash.

15. High N is positively correlated with high organic P, irrespective of the amount of total P present. High N is therefore necessary for synthesis of phosphatic organic substances.

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In connection with the vast amount of chemical analyses and the recording of other data during the six year period, the valuable services of E. L. Marais, A. J. v.d. Merwe, A. C. Bathurst, E. M. Nyenhuis, O. T. van Niekerk, T. C. de Waal and N. H. Shaw are acknowledged.

The African Realty Trust, on whose estate these fertilizer trials were carried out, are thanked for their generous co-operation in connection with the field work throughout this investigation.

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BOOK REVIEWS

AN OUTLINE OF CYTOLOGICAL TECHNIQUE FOR PLANT BREEDERS. Imperial Bureau of Plant Genetics. (Cambridge. 1s. 6d.)

As Sir Daniel Hall says, in a brief Foreword to this Bulletin, a knowledge of cytology and some acquaintance with its methods has become essential to the plant breeder. The Bulletin aims at giving an account of the standard methods used in plant cytology based on practical experience. After an introduction dealing with the value of cytology in plant breeding and some general remarks on methods, the Bulletin describes the paraffin method (including staining with iron alum-haematoxylin and with gentian violet), the aceto-carmine method and smears with standard fixatives and stains. Hints on the use of the microscope, a list of fixatives, with formulae, and a short list of literature references are given. The Bulletin is suitable not only for plant breeders but also for anyone wishing to learn standard methods.

THE PESTS OF FRUITS AND HOPS. By A. M. Massee, D.Sc. (Crosby, Lockwood & Son Ltd., London, 1937. pp. 294; 26 plates. Price 15/-.)

For nearly thirty years, Theobald's " Insect Pests of Fruit " has been invaluable as *the* book of reference on the subject, but there can be no question that a new account of the insect and allied pests of fruit and hops and of present-day methods for their control was badly needed. No one is better qualified than Dr. Massee to undertake the task of filling this evident gap and the appearance of his book is very welcome.

It is essentially a practical book. The chief fruit crops are considered in turn, each chapter beginning with a list of the pests, giving the parts of the plant attacked and a note of the page on which the pest is discussed, so that reference to any particular insect can quickly be made. A short general account of each pest is followed by notes on the life cycle and sections on recognition in the field and on control measures. Detailed descriptions of insects are, however, omitted and the author has succeeded in avoiding almost completely the use of technical terms, without loss of accuracy. The information necessary for identification of the pests in the field is very clearly presented, emphasis being laid rather on the nature of the injury caused than on the appearance of the pest concerned, and the text is amplified by the numerous admirable photographs contributed to the book by Mr. R. M. Greenslade. Many insects which are not normally important enough from an economic point of view to justify employment of control measures are dealt with briefly and it is valuable to have

these included, for "minor" pests may and do sometimes become "major" pests if only locally. Finally, there are chapters on Beneficial and Harmless Insects, on Insecticides and on Spraying Equipment and Methods, the last written by Mr. J. Turnbull; and seperate general indexes of the popular and scientific names of the pests are provided. The book is well produced and there is a noticeable absence of misprints.

Readers of Dr. Massee's book cannot fail to appreciate the notable advances that have taken place in recent years in the measures available for control of many of our most important fruit pests and, as pointed out in the preface, the co-operation of chemists with biologists is an important factor contributing to this advance. It is satisfactory that he is able to write (p. 244):—

> "Thanks to the modern methods of pest control, the Hop-Damson Aphis, or 'Hop Fly', is no longer a continual source of worry to the hop grower during the summer months. Until some ten years ago, however, it was undoubtedly one of the most important insect pests associated with hops, while the damage it caused to damson and plums was no less severe. . . .
>
> "To-day the Hop-Damson Aphis is a very secondary pest, and it is very rarely met with in a well-kept garden";

and there are similar remarks with respect to Apple Aphides, Apple Sucker, Black Currant Gall Mite and other well-known pests. On the other hand, there remain an abundance of unsolved problems, and the unsatisfactory nature of present control measures for certain common pests—as, for example, the Apple Blossom Weevil—and the insufficiency of our information about others, such as Strawberry Eelworm, are frankly admitted. In the chapter on beneficial species, attention is specially drawn to predacious insects which are of more importance than is commonly realized and to the unfortunate effect of certain control measures in reducing their numbers, a subject that might well receive more adequate investigation.

It would be easy, but unnecessary in this Journal, to continue at length enumerating points of particular interest. Reference must, however, be made to the short account of insecticides and their application in Chapter XIV. Growers especially will find this of interest and value. The chemical aspect of the subject is not touched on, but the various types of oil washes, lime sulphur, lead arsenate, nicotine, derris and pyrethrum, as well as soft soap and other wetters and spreaders, are briefly discussed in an exceedingly practical manner. The author is uncompromising in his opinion that tar distillate washes should be applied every year. He says (p. 263):—

> "In view of the number of spray applications that are recommended to-day, the commercial growers frequently inquire whether it would be a practical proposition to omit the tar oil in some seasons. It would not";

and proceeds to give his reasons. The need for caution in using summer petroleum washes owing to the risk of damage to foliage and fruit is emphasized, but the author anticipates that the present tar-petroleum mixed washes will be improved before long and the number of pests controllable by one spraying in the winter thus increased. Some day, insecticides may become unnecessary and we may find out how to grow plants highly resistant to all pests and diseases. "Pending this millennium, however, we have to make the best of whatever knowledge is available, and in its application the sprayer still of necessity plays a principal part."

Dr. Massee writes clearly and concisely and almost every page bears evidence of his close personal acquaintance, both in the field and under laboratory conditions, with the habits of the pests he is describing. This gives to the book a special individual character and it is very far removed from a mere compilation of facts, though the literature of the subject and the work of other investigators has by no means been neglected. The author's special knowledge of the problems of pest control as they affect fruit-growers in Kent has naturally influenced his treatment of the subject, but he has put entomologists and growers everywhere in his debt by placing at their disposal this authoritative account of the pests of fruit and of hops. It is a pleasure to commend the book to the attention of all interested in fruit growing.

C.T.G.

SCIENTIFIC HORTICULTURE. Edited by R. T. Pearl. Vol. 5, pp. 196. Wye: South-Eastern Agricultural College, February, 1937. Price 3s. 6d. net (postage 5d. extra).

In this Volume research workers will be interested in the two articles by T. Whitehead and the late W. M. Davies, of University College, Bangor, on virus problems in relation to seed potato production in North Wales. R. W. Marsh, Long Ashton, contributes a refreshingly concise account of recent American work on copper fungicides. F. Kidd and C. West, Cambridge, describe the main phases in the development of the Bramley apple, and present experimental data in support of the tradition that the right time to pick the apple for storage is when it will yield to a gentle twist of the stalk. Prof. R. H. Stoughton, Reading, in reviewing the problem of bud dormancy, surveys the field of research without encroaching unduly on the ground covered elsewhere in this Volume by O. N. Purvis, London, in an article on recent Dutch investi-

gations into the temperature requirements of hyacinths, and by M. Thomas, Newcastle, in a discussion of recent work on plant hormones.

W. J. C. Lawrence contributes an interesting summary of twenty-five years' research at the John Innes Horticultural Institution, to which an appendix by Miss B. Schafer is added containing a report-summary of current work there. On the more strictly practical side, W. Corbett outlines the history of the pot plant industry in this country, whilst other descriptive articles deal with commercial horticulture in Essex and Middlesex by H. Fraser and P. E. Cross, respectively, and growing fruit in North Wales by H. Taylor. B. S. Furneaux and W. G. Kent have an interesting note on the cause of a collapse of fruit trees shortly after coming into leaf, locally known as " The Death " and due to root suffocation.

The Volume covers a wide range and provides up-to-date information on many horticultural subjects of particular interest to research workers, advisory officers and students.

N.B.B.

HORTICULTURAL ASPECTS OF WOOLLY APHIS CONTROL TOGETHER WITH A SURVEY OF THE LITERATURE. By R. M. Greenslade. (Tech. Comm. Imperial Bureau of Fruit Production, East Malling, Kent, England, 8, 1936, pp. 88, bibls. 555 (general) and 156 (biologic control). 2s. 6d.)

The voluminous literature published during the last hundred years on Woolly Aphis or American Blight and the divergent opinions expressed in it have long demanded examination and critical analysis. In November, 1933, a Memorandum and Questionnaire on the incidence and control of the pest was circulated by the Imperial Bureau of Fruit Production to all the apple growing countries of the world and co-operation invited.

The literature and the replies to the Questionnaire have been thoroughly sifted by the author, who, having devoted himself for some years to the Woolly Aphis problem in its many aspects, is in an exceptionally good position for the task.

First, the insect and its habits, its spread in the orchard, its methods of feeding and its possible alternative hosts are dealt with. Next, the bearing of climatic factors, temperature, humidity, wind and sunlight, on its incidence is considered. Control measures are considered in detail: (1) Artificial control including spraying, fumigation, tree injection, cultural practice, etc.; (2) Natural control by *Aphelinus mali* and other parasites; (3) Control by use of resistant stocks and varieties. A particularly interesting account is given of existing resistant varieties, of the breeding work in progress in England and

of the few indications afforded as yet of the possible causes of resistance ; (4) Control by legislation, e.g. quarantine measures, etc.

The literature from nearly 300 sources is further dealt with in two annotated lists which follow. The first, general, contains 555 references, while the second contains 156 references to articles on the biological control of the pest.

Finally, the Memorandum and Questionnaire mentioned above are reproduced in full, and a list of persons who replied is given. This list forms, incidentally, a useful index of workers interested in the subject.

Both to investigators and growers this publication should prove of great value.

VEGETATIVE PROPAGATION OF TROPICAL AND SUB-TROPICAL FRUITS. By G. St. Cl. Feilden and R. J. Garner. (Tech. Comm. Imperial Bureau of Fruit Production, East Malling, Kent, England, 7, 1936, pp. 67, bibl. 123. 2s.)

This compilation forms the second of a series of articles issued by the Imperial Bureau of Fruit Production on the vegetative propagation of tropical and sub-tropical horticultural crops, the first on citrus having appeared in 1932.

It is based on a thorough examination of existing literature and on the answers to enquiries sent to many workers in the tropics. It is in two parts. In the first will be found an illustrated and simple account of the different operations of budding, grafting, etc., referred to later. This is very welcome, in view of the looseness with which certain propagation terms are used in different parts of the English speaking world. An account follows of the methods commonly recommended for use or trial in the asexual propagation of some one hundred types of fruit, and references are given to the source of the information in each case.

The bibliography concerned precedes a useful index in which both common and scientific names of the plants discussed are included. The publication should prove a useful reference work to the tropical horticulturist.